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CITY OF BURBANK
TECHNICAL REPORT
SEISMIC SAFETY ELEMENT

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City planning Burbank
Emerg. relief Earthquakes

Prepared by:

ENVICOM CORPORATION

July 1974

PLATE I
SEISMIC / GEOLOGIC
RISK RATING MAP
JULY 1974

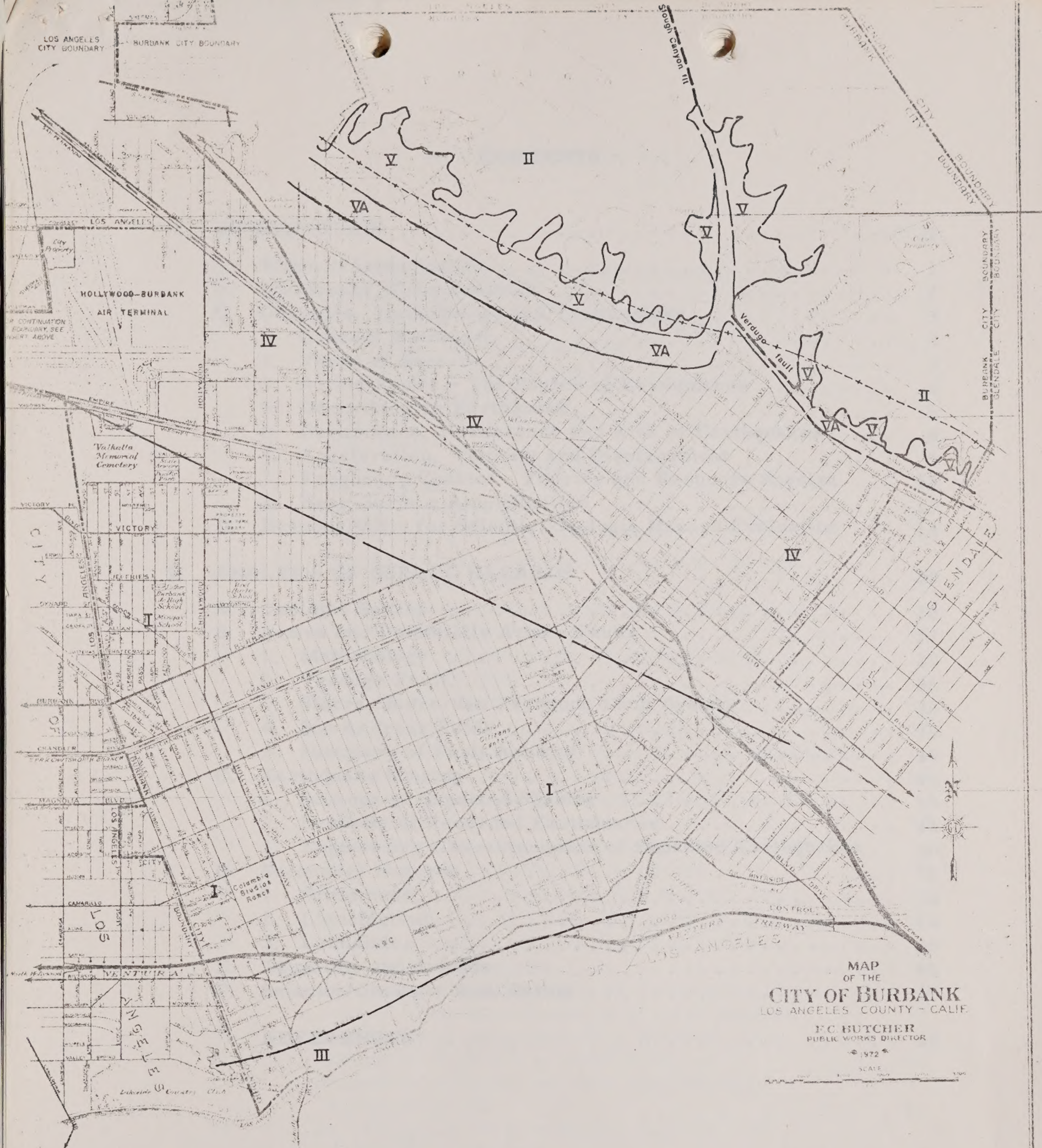
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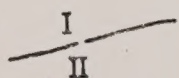
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LEGEND



Zone boundary. (See page 57)

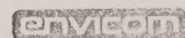
Fault; dashed where approximately located. (See pages 35-37)

Axis of gravity "high". (See page 36)

PLATE I

SEISMIC / GEOLOGIC RISK RATING MAP

JULY 1974





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I INTRODUCTION

A. SCOPE OF INVESTIGATION

Section 65302 (f) of the Government Code requires a Seismic Safety Element of all city and county general plans as follows:

"A seismic safety element consisting of an identification and appraisal of seismic hazards such as susceptibility to surface ruptures from faulting, to ground shaking, to ground failures, or to the effects of seismically induced waves such as tsunamis and seiches.

The seismic safety element shall also include an appraisal of mudslides, landslides, and slope stability as necessary geologic hazards that must be considered simultaneously with other hazards such as possible surface ruptures from faulting, groundshaking, ground failure and seismically induced waves."

The Guidelines (California Council on Intergovernmental Relations, 1973) for the preparation of local general plans states that:

"The intent is that all seismic hazards are to be considered, even though only ground and water effects are given as specific examples. The basic objective is to reduce loss of life, injuries, damage to property, and economic and social dislocations resulting from future earthquakes."

Based on the interpretation of the intent of the law, the Guidelines define the scope of the Element as including:

1. A general policy statement.
2. The identification, delineation and evaluation of natural seismic hazards.
3. The consideration of existing structural hazards.
4. An evaluation of disaster planning program.
5. The determination of specific land use standards related to level of hazard and risk.

INTRODUCTION

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2. The identification, definition and evaluation of natural seismic hazards.
3. The consideration of existing structural hazards.
4. An evaluation of disaster planning programs.
5. The determination of specific land use standards related to level of hazard and risk.

The Guidelines indicate that the identification of natural seismic hazards should include the following:

- "1. General structural geology and geologic history.
2. Location of all active or potentially active faults, with evaluation regarding past displacement and probability of future movement.
3. Evaluation of slope stability, soils subject to liquefaction and differential subsidence.
4. Assessment of potential for the occurrence and severity of damaging ground shaking and amplifying effects of unconsolidated materials.
5. Identification of areas subject to seiches and tsunamis.
6. Maps identifying location of the above characteristics."

The following technical evaluation is intended to meet or exceed these requirements.

B. PHILOSOPHY OF THE ANALYSIS

The quantitative study of the strong shaking of earthquakes is a relatively young science. It was begun in California in the early 1930's, but has been limited by the necessity of having the right instruments in the right place when a significant earthquake does occur. Much information has been acquired over the last 40 years, but there are significant gaps and much remains to be learned.

With this relatively limited level of basic data, two different approaches to the development of a Seismic Safety Element are available. One can utilize broad generalizations to describe expected events; certainly the inadequacies of the data favor this approach. On the other hand, if the results are to be used by engineers in designing safer structures, then a commitment to mathematical form is necessary. To this end, the analysis is developed in this way, whenever possible, and presented in chart or graph form. Qualitative descriptions of the results are included for the lay reader, and a brief discussion of methodology, terminology and concepts is included in Section C. A Glossary of Terms for reference purposes is included at the back of the report.

The basic philosophy within which this analysis has been developed is that the intent of the Seismic Safety Element is to plan and prepare for the future based on what we know today rather than waiting until we know all that we would like to know.

C. CONCEPTS, METHODOLOGY AND TERMINOLOGY

1. General Statement

The Seismic Safety Element is probably the most technically-oriented of all the mandated elements of the General Plan. For this reason, and because of the wider range of backgrounds and experience of expected readers, it is appropriate to include in the Introduction a discussion of concepts, methodology and terminology to be used in developing the technical base for this element. This discussion is intended to supply not only a dictionary-function of technical terms and concepts, but, most important, to establish the systematic cause-and-effect relationships between the several seismic hazards, and the need for a systematic analysis of available information.

The topics discussed in the following sections of the introduction are arranged in an order that becomes increasingly more difficult for the layman. Sections 2 through 4 discuss concepts and terms commonly included in newspaper accounts of earthquakes, while later sections discuss the concepts necessary in the technical analysis of earthquake hazards. The latter are intended primarily for readers with engineering or scientific backgrounds, but may also be of interest of the lay reader.

The text of the report is arranged in a similar order. Each section becomes increasingly more complex, and the later sections are intended to document the analysis for engineers and earth scientists who may wish to expand on or apply the data to the detailed analysis of individual sites.

2. Types of Hazards

The several seismic hazards discussed in the C. I. R. Guidelines can be grouped as a cause-and-effect classification that is the basis for the order of their consideration. Earthquakes originate as the shock wave generated by movement along an active fault. The primary natural hazards are ground shaking and the potential for ground rupture along the surface trace of the fault. Secondary natural hazards result from the interaction

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of ground shaking with existing ground instabilities, and include liquefaction, settlement and landslides. In this context, tsunamis, or "tidal waves", and seiches would be primary natural hazards.

The potentially damaging natural events (hazards) discussed above may interact with man-made structures. If the structure is unable to accommodate the natural event, failure will occur. The potential for such failure is termed a structural hazard, and includes not only the structures themselves, but also the potential for damage or injury that could occur as the result of movement of loose or inadequately restrained objects within, on, or adjacent to a structure.

3. Active Faults — The Source of Earthquakes

Earth scientists are generally agreed that earthquakes originate as the result of an abrupt break or movement of the rock in the relatively brittle crust of the earth. The earthquake is the effect of the shock waves generated by the break, much the same as sound waves (a noise) are generated by breaking a brittle stick. If the area of the break is small and limited to the deeper part of the crust, the resulting earthquake will be small. However, if the break is large and extends to the surface, then the break can result in a major earthquake.

These breaks in the earth's crust are called faults. In California, faults are extremely common, and vary from the small breaks of an inch or less that can be seen in almost any road-cut, to the larger faults such as the San Andreas on which movement over many millions of years has amounted to hundreds of miles. In addition to the size of faults, their "age" is also important. Many large faults have not moved for millions of years; they are considered "dead" or no longer active. They were probably the source of great earthquakes millions of years ago, but are not considered dangerous today.

Since faults vary as to the likelihood of their being the source of an earthquake, considerable effort has, and is continuing to be expended by geologists and seismologists to determine and delineate the faults likely to generate significant earthquakes. The C.I.R. Guidelines define an active fault as one that "has moved in recent geologic time and which is likely to move again in the relatively near future. Definitions for planning purposes extend on the order of 10,000 years or more back and 100 years or

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more forward." In this definition, "has moved" would normally be taken to mean demonstrable movement at the surface.

The State Mining and Geology Board (1973), for purposes of the Alquist-Priolo Geologic Hazards Zone Act (Chapter 7.5, Division 2, Public Resources Code, State of California) "regards faults which have had surface displacement within Holocene time (about the last 11,000 years) as active and hence as constituting a potential hazard."

The State Geologist (Slosson, 1973, Explanation of Special Studies Zones Maps, p. 3 & 4) defines a potentially active fault as one "considered to have been active during Quaternary time (last 3,000,000 years) -- on the basis of evidence of surface displacement." The State Geologist notes the contrast with the State Mining and Geology Board, but also states: "An exception is a Quaternary fault which is determined, from direct evidence, to have become inactive before Holocene time (last 11,000 years)."

The definitions above are compatible if taken in the following sequence:

1. A potentially active fault is one which exhibits evidence of surface displacement during Quaternary time (last 3,000,000 years approximately).
2. A potentially active fault will be considered as an active fault if there is evidence of surface displacement during Holocene time (last 11,000 years, approximately).
3. A potentially active fault will be considered as inactive if, by direct evidence, it can be shown that there has been no displacement during Holocene time.

The key to the practical application of the above definitions is the placement of the burden of proof. The State Geologist will consider a fault as potentially active if there is evidence of surface displacement during Quaternary time. If a fault is so designated as required by the Alquist-Priolo Act, then the burden of proof shifts to the developer to show by "direct evidence" that the fault has not been active (i.e. no surface displacement) during Holocene time. The practical application of this system of evaluation will depend primarily on the interpretation of "direct evidence" in the review and evaluation of the required geologic reports.

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The above discussion applies directly to Special Studies Zones as required by the Alquist-Priolo Act. To date no such zones have been established within the City of Burbank. However, the State Geologist is required to "continually review new geologic and seismic data" in order to revise established zones and to delineate additional zones. In this context, evidence of fault activity in the Burbank area will be discussed herein utilizing the framework of evaluation as provided by the State Geologist and the State Mining and Geology Board. Additional comment on the responsibility for evaluation of geologic/seismic hazards is included in Section D of this Introduction, and also as pertinent in that part of the text covering the evaluation of active and potentially active faults.

4. Describing an Earthquake

Several terms are used to describe the location, "size", and effects of an earthquake. A clear understanding of the meaning of these terms and their limitations is essential to an understanding of the results of the investigation.

The location of an earthquake is generally given as the epicenter of the earthquake. This is a point on the earth's surface vertically above the hypocenter or focus of the quake. The latter is the point from which the shock waves first emanate. However, as discussed above earthquakes originate from faults. These are surfaces not points, so the hypocenter is only one point on the surface that is the source of the earthquake.

Magnitude describes the size of the earthquake itself. Technically it is defined as the log of the maximum amplitude as recorded on a standard seismograph at 100 kilometers (62 miles) from the epicenter. The most important part of this definition is that it is a log scale; that is, an increase of 1 on the magnitude scale (e.g. magnitude 5.0 to 6.0) represents an increase of 10 in the amplitude of the recorded wave.

Intensity describes the degree of shaking in terms of the damage at a particular location. The scale used today is the Modified Mercalli Scale of 1931, and is composed of 12 categories (I to XII) of damage as described in Table 1. The Roman numerals are used to emphasize that the units in the scale are discrete categories rather than a continuous numerical sequence as is the magnitude scale. It is important to remember that intensity is a very general description of the effects of an

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TABLE 1. MODIFIED MERCALLI INTENSITY SCALE OF 1931
(from United States Earthquakes)

Intensity	Description of Damage
I	Not felt except by a very few under specially favorable circumstances. (I Rossi-Forel Scale)
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel Scale)
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel Scale)
IV	During the day, felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (IV to V Rossi-Forel Scale)
V	Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel Scale)
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel Scale)
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerably in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars. (VIII Rossi-Forel Scale)
VIII	Damage slight in specially designed structures; considerable in ordinary, substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed. (VIII to IX Rossi-Forel Scale)
IX	Damage considerable in specially designed structures; well-designed, frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX Rossi-Forel Scale)
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with their foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel Scale)
XI	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into air.

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I	Not felt except by a very few under specially favorable circumstances (I Rossi-Forel Scale)
II	Felt only by a few persons at rest, especially on upper floors of buildings Objectively suspended objects may swing (II to II Rossi-Forel Scale)
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel Scale)
IV	During the day, felt indoors by many, outdoors by few. At night, some awakened. Crockery, dishes, doors disturbed, walls make cracking sound. Motion of heavy truck striking building. Standing motorcars rocked noticeably. (IV to V Rossi-Forel Scale)
V	Felt by nearly everyone, many awakened. Some dishes, windows, etc. broken; a few instances of cracked plaster; sensitive objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel Scale)
VI	Felt by all, many frightened and some heavy furniture moved; a few instances of fallen plaster in damaged chimneys. Damage slight. (VI to VII Rossi-Forel Scale)
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars. (VII to VIII Rossi-Forel Scale)
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Fane! walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed. (VIII to IX Rossi-Forel Scale)
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX to X Rossi-Forel Scale)
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with their foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifting sand and mud. Water splashed (sprayed) over banks. (X to XI Rossi-Forel Scale)
XI	Few, if any, (masonry) structures remain standing. Bridges destroyed. Ground fissures in groups. Underground pipes completely out of service. Earth shrugs and land slips in soft ground. Lands heat greatly.
XII	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown into air.

earthquake, and depends not only on the size of the quake and the distance to its center but also on the quality of the construction that has been damaged and the nature of local ground conditions.

5. Occurrence, Recurrence and Risk of Earthquakes

Earthquakes have had in the past a certain occurrence in space and time. These occurrences may or may not set certain patterns that can form the basis for predicting their occurrence in the future. When such occurrences are analyzed in time, certain characteristics may statistically recur at definite intervals. If it can be shown that a particular magnitude earthquake recurs on a fault on the average of once in a certain time interval, then that interval is said to be the recurrence interval for that magnitude. Or, if the interval of time is set (e.g. a 100-year period), then earthquakes of a particular magnitude may recur a certain number of times in the specified period. This number is then the recurrence rate for that magnitude.

In California small earthquakes occur much more often than large earthquakes. Also, there is a fairly definite pattern in that the log (base 10) of the number of events of a particular magnitude that have occurred in the part is approximately proportional to the magnitude of those events. This relationship appears to apply to larger areas such as California and western Nevada, some smaller areas such as the Los Angeles Basin, the Imperial Valley, etc., and to some faults. However, this relationship does not necessarily apply to all faults, and it should be applied to small areas, such as cities or individual sites, with great care.

Recurrence intervals can be used to indicate the risk of an earthquake in much the same way that recurrence is used to describe the risk of flooding (e.g. 100-year flood). There is one important difference, however. Flood is the result of a random combination of meteorological events, whereas current geologic theory indicates that the buildup of the strain released during an earthquake is more likely to be regular. This regularity suggests that prediction, to varying degrees, may be possible depending on the extent of understanding of a particular fault. In some cases this understanding is limited to a statistical regularity in the number and magnitude of earthquakes generated. For others, such as the San Andreas fault, much more is known on which to base an estimate of the risk involved. For others, little more is known other than that there is some degree of hazard involved.

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6. Acceleration, Velocity and Displacement

The data of seismologists and geologists are, in general, not applicable to the engineering design of earthquake-restraint structures. The seismograph, for example, is a very sensitive instrument designed to record earthquakes at great distances. A level of shaking that would be meaningful to an engineer in designing a building would put most seismographs completely off-scale.

As a result, it has been necessary to design and install special instruments to record the strong motions of earthquakes that are of interest to the engineer in the design of earthquake-restraint structures. The first such instruments, principally accelerographs and seismoscopes, were installed by the U.S. Coast and Geodetic Survey in the late 1920's. Since that time, the instrumentation and analytical techniques have been continuously improved, and many excellent records have been obtained of the more recent strong earthquakes.

The following sections are a brief introduction to the concepts, data and application of strong-motion records. The science is relatively young, and is growing in bursts that follow the recording of a damaging earthquake.

The accelerograph is a short-period instrument (in contrast to the seismograph), and measures the acceleration of the ground or the structure on which it is mounted. Figure 1 shows the ground acceleration recorded just a few hundred feet from the slipped fault during the 1966 Parkfield earthquake. The velocity and displacement curves have been derived from it by integration. It is particularly good example of the relationships of these three parameters of motion because of the relatively "clean", single-displacement pulse that corresponds to two velocity peaks and four acceleration peaks. Figure 2 shows the more typically complex record of the San Fernando earthquake as recorded at Pacoima Dam. Neither of the two, however, are typical records in terms of accelerations recorded. The Pacoima record shows the largest acceleration recorded to date (1.25g), and the Parkfield record (0.5g) was the largest recorded in the United States before the San Fernando earthquake.

It should also be noted that accelerographs normally record three components; two in the horizontal plane at a right angle to each other, and one vertical. Only one component is shown in each of the two examples.

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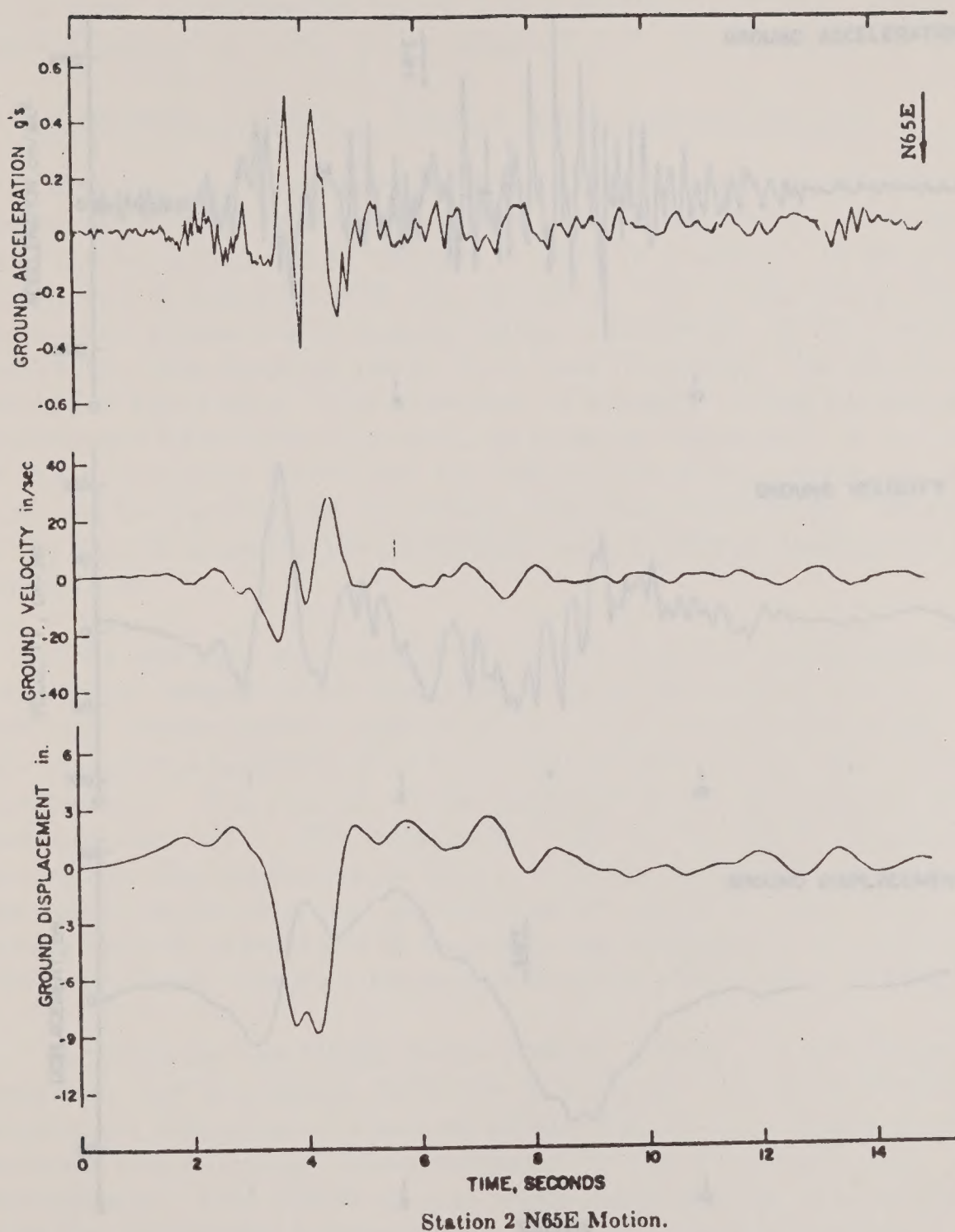


Figure 1. Ground acceleration, velocity and displacement.
1966 Parkfield earthquake.

from Housner & Trifunac, 1967.

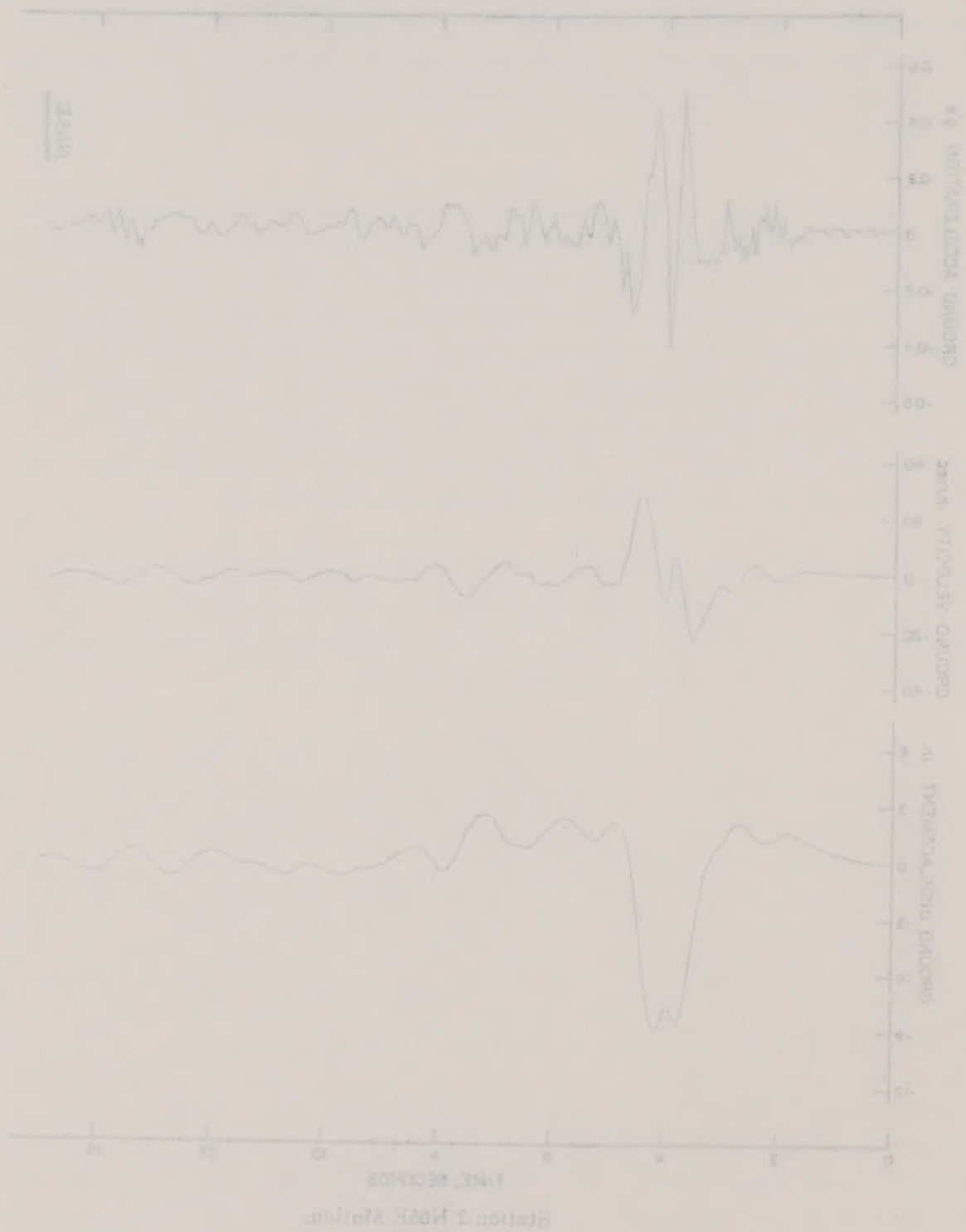


Figure 1. Ground acceleration, velocity and displacement.
1968 Parkfield earthquake.

from Housner & Trifunac, 1967.

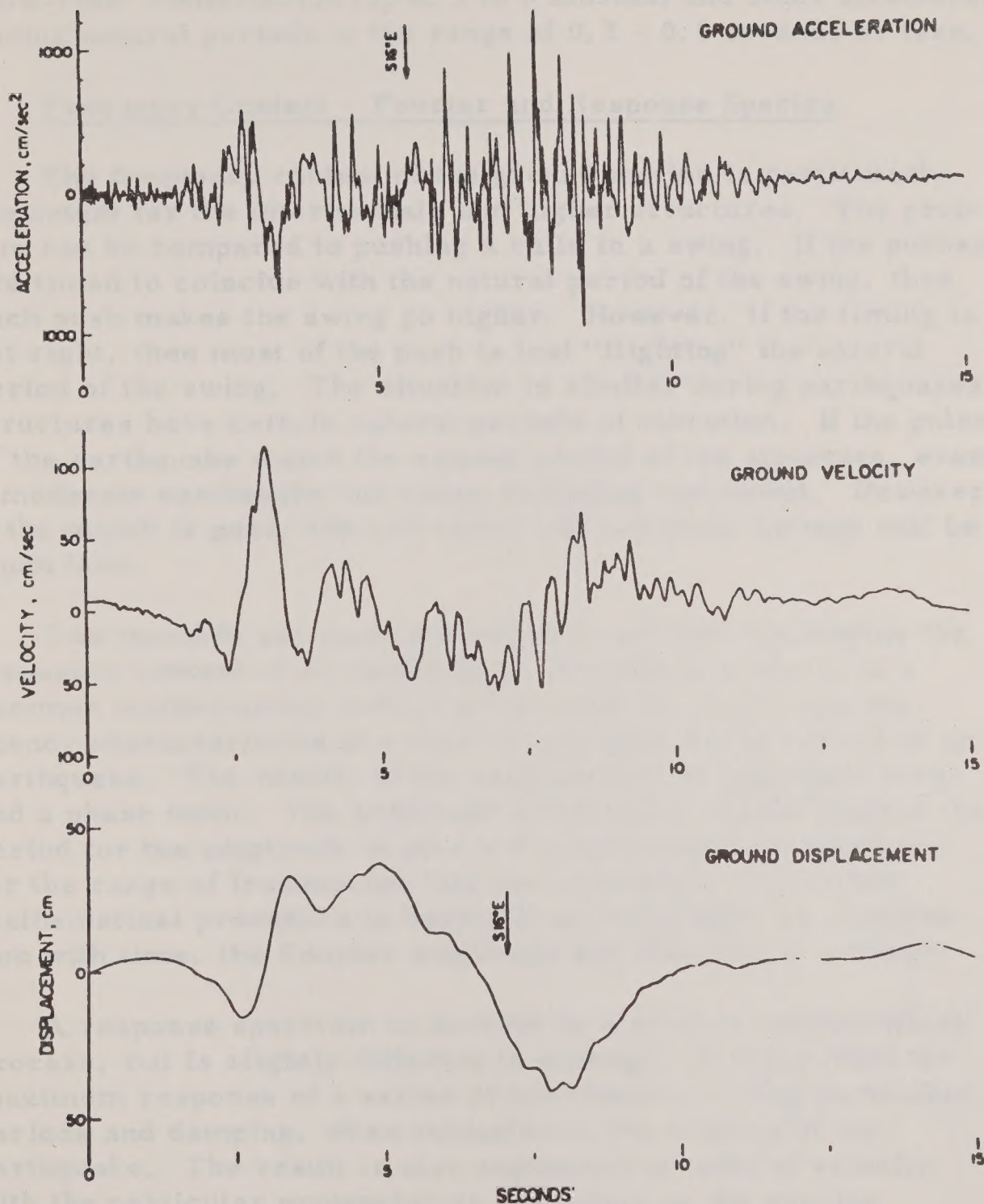


Figure 2. Acceleration, velocity and displacement in the S16° E direction during the main event of the San Fernando earthquake of February 9, 1971, 06:00 (PST).

from Trifunac & Hudson, 1971.

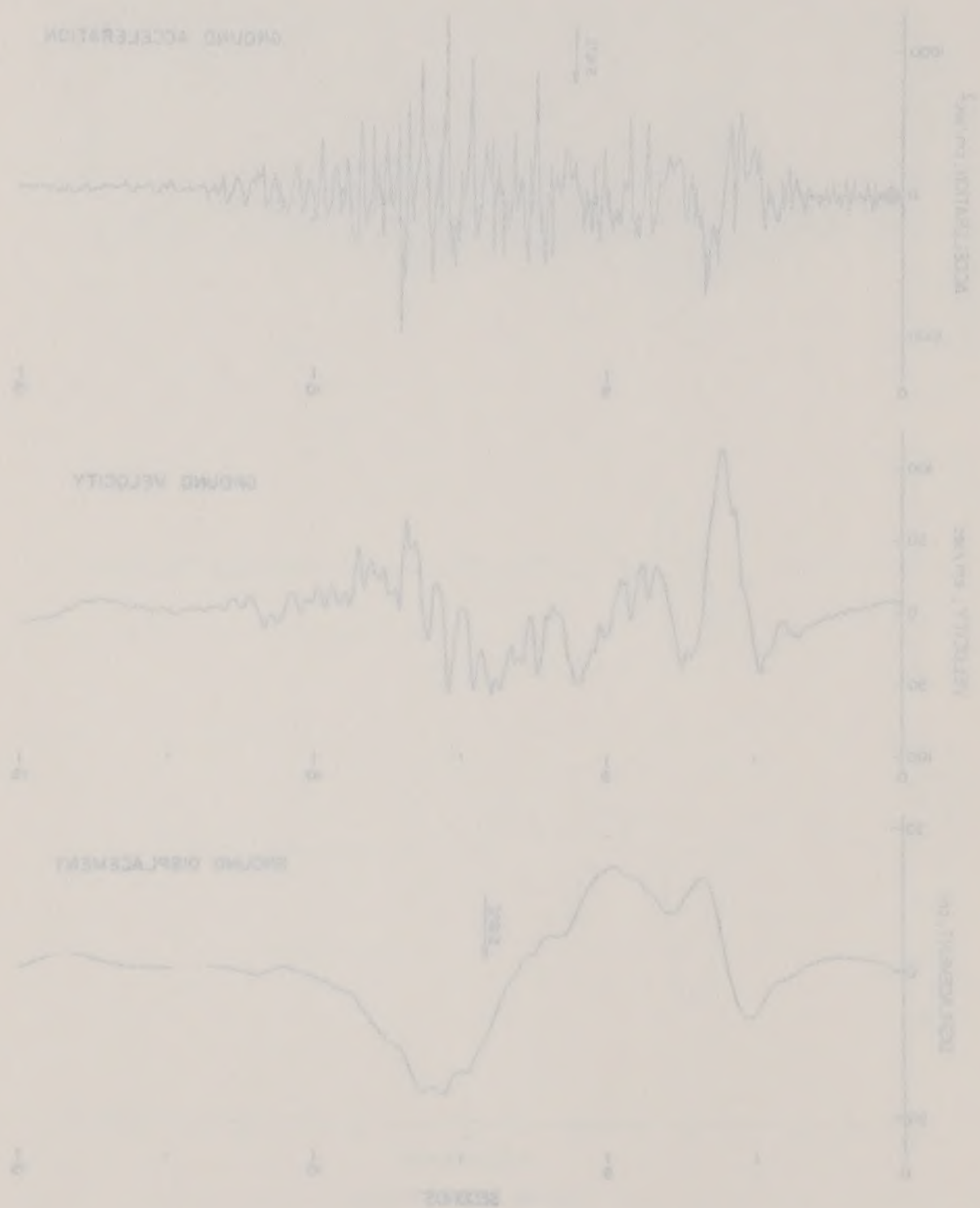


Figure 2. Acceleration, velocity and displacement in the S15° E direction during the main event of the San Fernando earthquake of February 9, 1971, 06:00 (PST).

from Trifunac & Hudson, 1971.

Maximum acceleration is one of the basic parameters describing ground shaking, and has been the one most often requested by agencies such as FHA in determining the earthquake hazard to residential structures. It is particularly important for "low-rise" construction (up to 3 to 5 stories) and other structures having natural periods in the range of 0.3 - 0.5 seconds or less.

7. Frequency Content - Fourier and Response Spectra

The frequency content of the ground motion is particularly important for the intermediate and higher structures. The problem can be compared to pushing a child in a swing. If the pushes are timed to coincide with the natural period of the swing, then each push makes the swing go higher. However, if the timing is not right, then most of the push is lost "fighting" the natural period of the swing. The situation is similar during earthquakes. Structures have certain natural periods of vibration. If the pulses of the earthquake match the natural period of the structure, even a moderate earthquake can cause damaging movement. However, if the match is poor, the movement and resulting damage will be much less.

Two methods are commonly used to analyze and display the frequency content of an earthquake. A Fourier analysis is a common mathematical method of deriving the significant frequency characteristics of a time-signal such as the record of an earthquake. The results of the analysis are an amplitude term and a phase term. The amplitude is normally plotted against the period for the amplitude to give a Fourier amplitude spectrum for the range of frequencies that are of interest. Since the mathematical procedure is basically an integration of acceleration with time, the Fourier amplitude has the units of velocity.

A response spectrum is derived by a similar mathematical process, but is slightly different in concept. It represents the maximum response of a series of oscillators, having particular periods and damping, when subjected to the shaking of the earthquake. The result is also expressed in units of velocity with the particular nomenclature depending on the precise method used to derive the spectrum.

The Fourier spectrum can be generally described as the energy available to shake structures having various natural frequencies. The response spectrum gives the effect, in maximum velocity, of this available energy on simple structures

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The Fourier spectrum can be generally described as the energy available to shake structures having various natural frequencies. The response spectrum gives the effect, in maximum velocity, of this available energy on simple structures

having various frequencies and damping. At zero damping the two are very similar. Figure 3 shows a plot of both the Fourier spectrum and the response spectrum with zero damping for the Taft earthquake of 1952. Figure 4 shows the response spectrum for the Parkfield record (Figure 1) for several levels of damping.

8. Near-Surface Amplification

The shock waves of an earthquake radiate outward from the source (i.e. the slipped fault) through the deeper and relatively more dense parts of the earth's crust. In this medium, the waves travel at high velocity and with relatively low amplitude. However, as they approach the surface, the velocity of the medium decreases and may become quite variable if layers of different rock types are present. The overall effect is generally an amplification of the wave or of certain frequencies within the spectrum of the wave.

The most consistently applicable effect is the increase in wave amplitude that accompanies the decrease in velocity. This relationship can be compared to laws of mechanics that require the conservation of energy and momentum. In the case of earthquake waves, the energy of velocity is transferred to energy of wave amplitude when the velocity decreases.

A second effect is the amplification of certain frequencies due to the thickness and velocity of near-surface layers of the earth. The geometry of these layers controls the frequency of shaking just like the geometry of a TV antenna controls the frequency it receives best. A striking example is the very high amplification of waves of 2.5-second period (Figure 5) by the stratification of the old lake beds on which Mexico City has been built. This concentration of the energy in a very narrow frequency range could be disastrous for structures with a matching natural period. Just like the child in the swing, they would move more and more with each successive pulse of the quake. Such pronounced amplifications are unusual, but if present, they can be extremely important.

D. RESPONSIBILITY FOR SEISMIC/GEOLOGIC HAZARD EVALUATION

The responsibility for the evaluation of seismic and geologic hazards lies with both the public and private sectors. The following are suggested as guidelines in determining the distribution of responsibility of the two sectors:

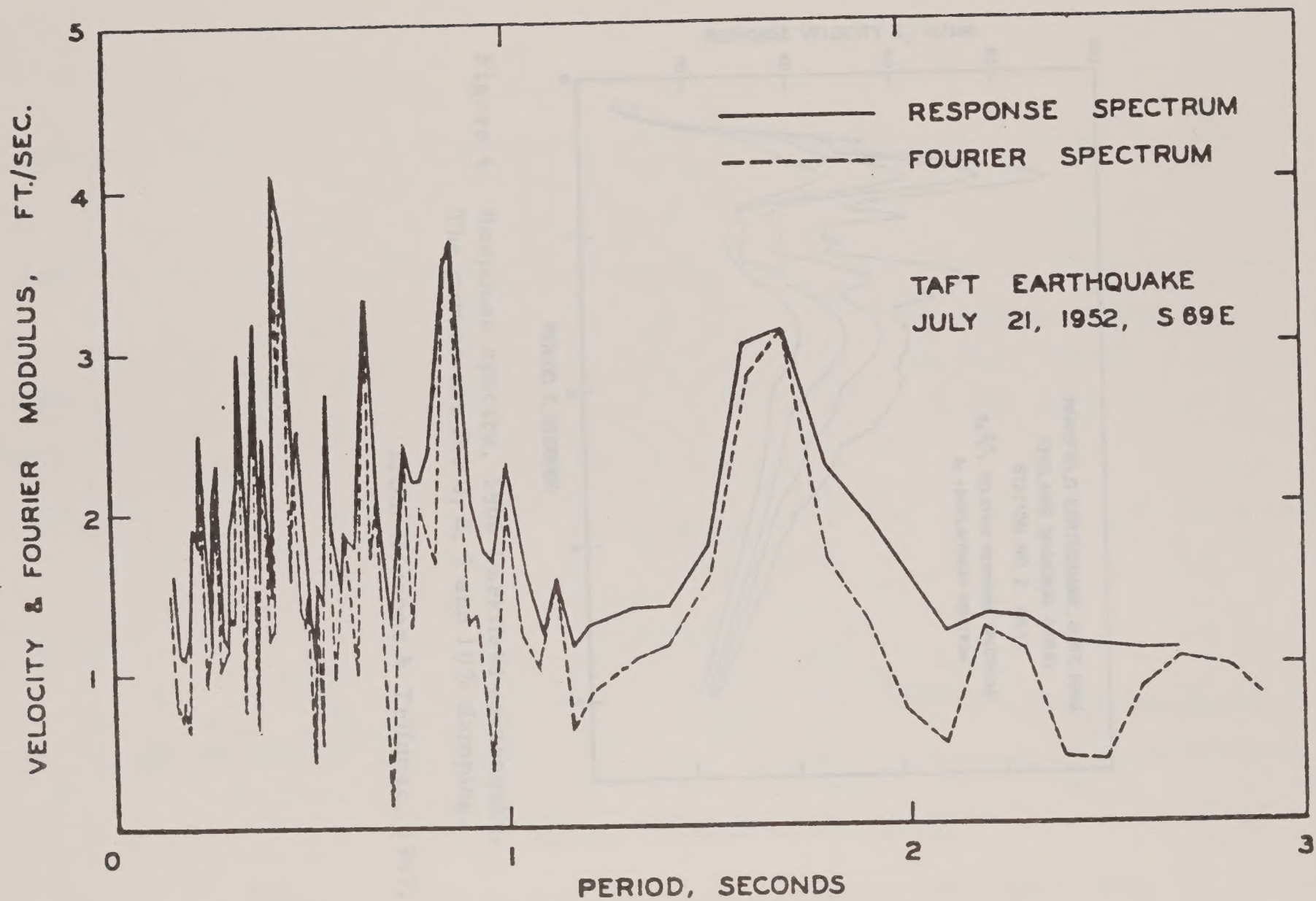


Figure 3. Fourier and response spectra, 1952 Kern County earthquake.

from Alford et al, 1964.

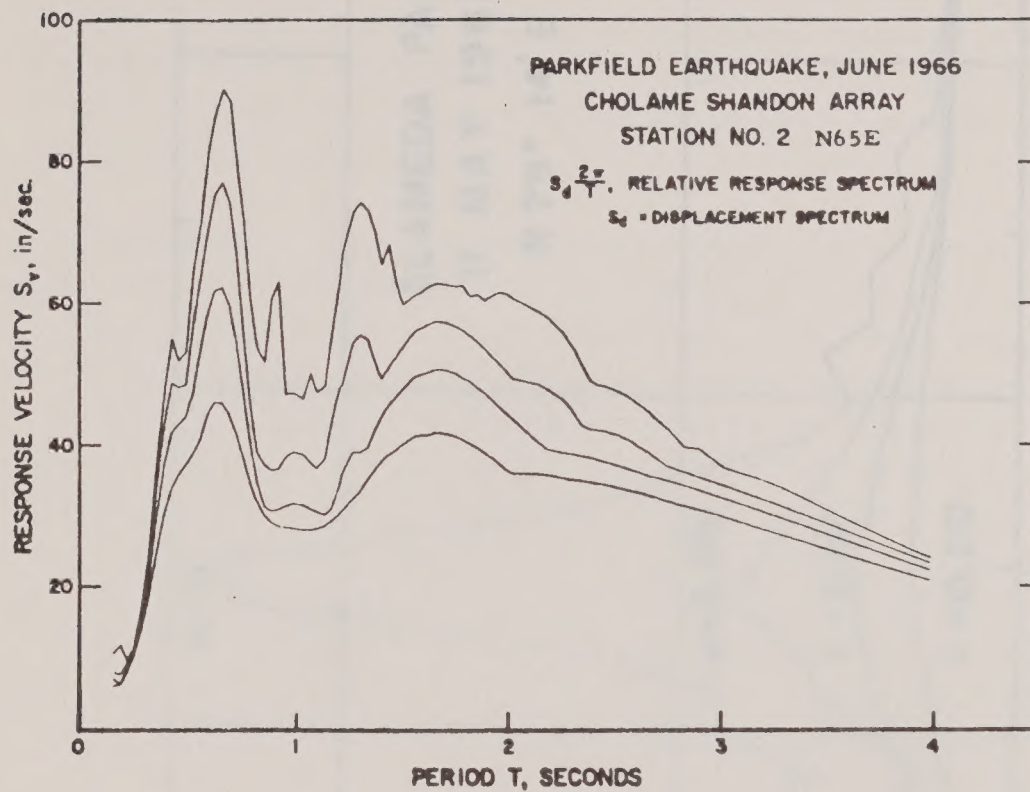


Figure 4. Response spectra, 1966 Parkfield earthquake.
 The curves are for 0, 2, 5 and 10% damping.

from Housner & Trifunac, 1967.

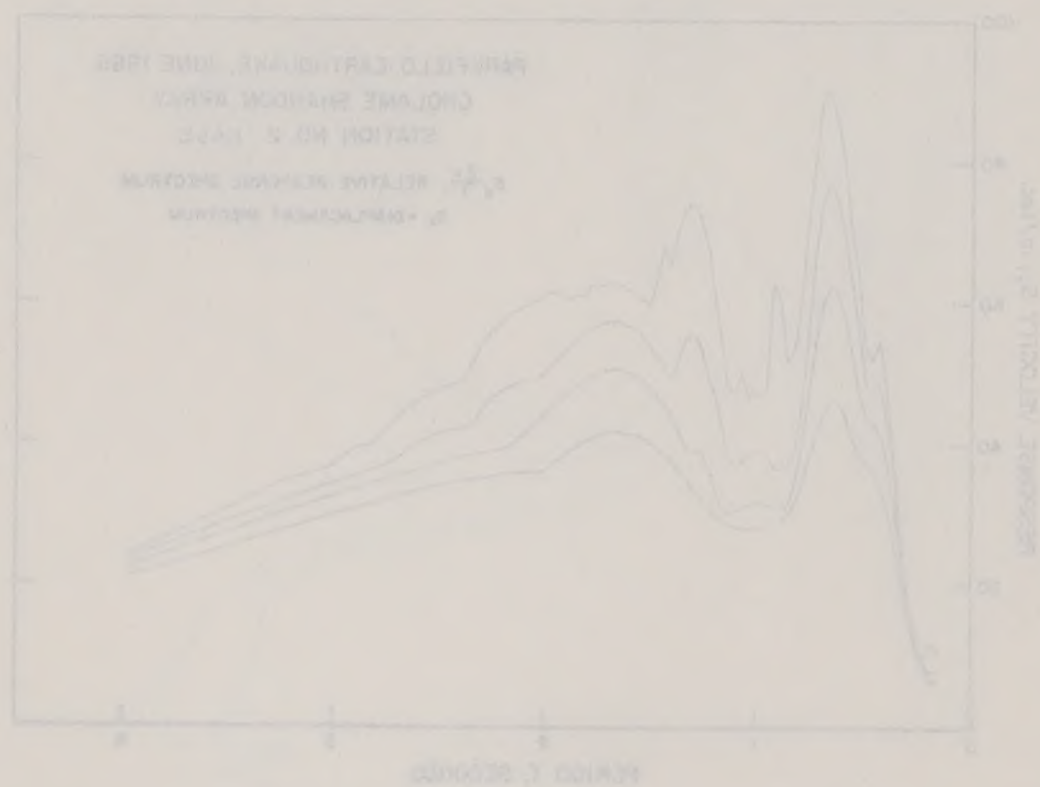


Figure 5. Response spectra, 1982 Parítilo earthquake. The curves are for 0, 5, and 10% damping.

From Housner & Yarnous, 1967.

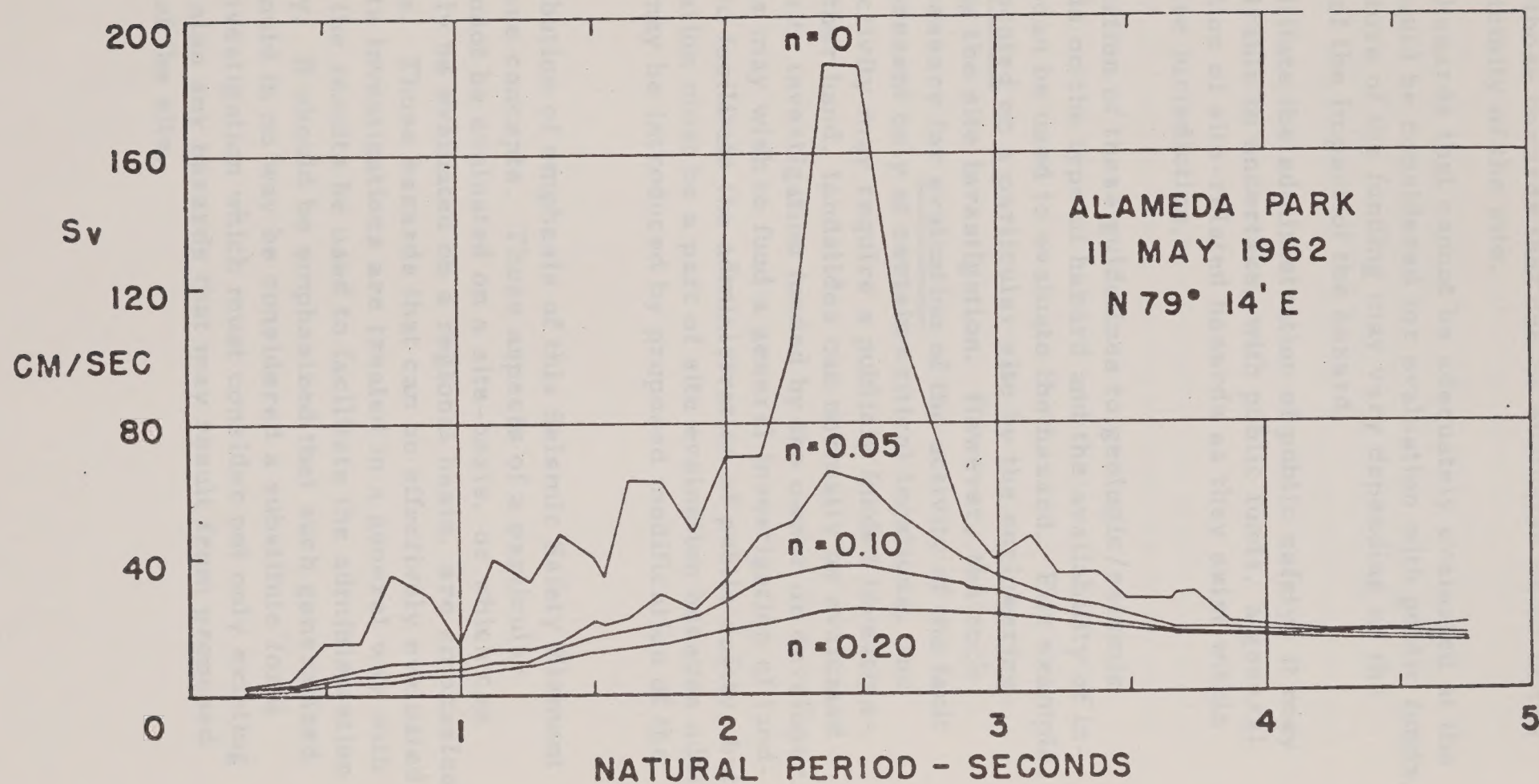
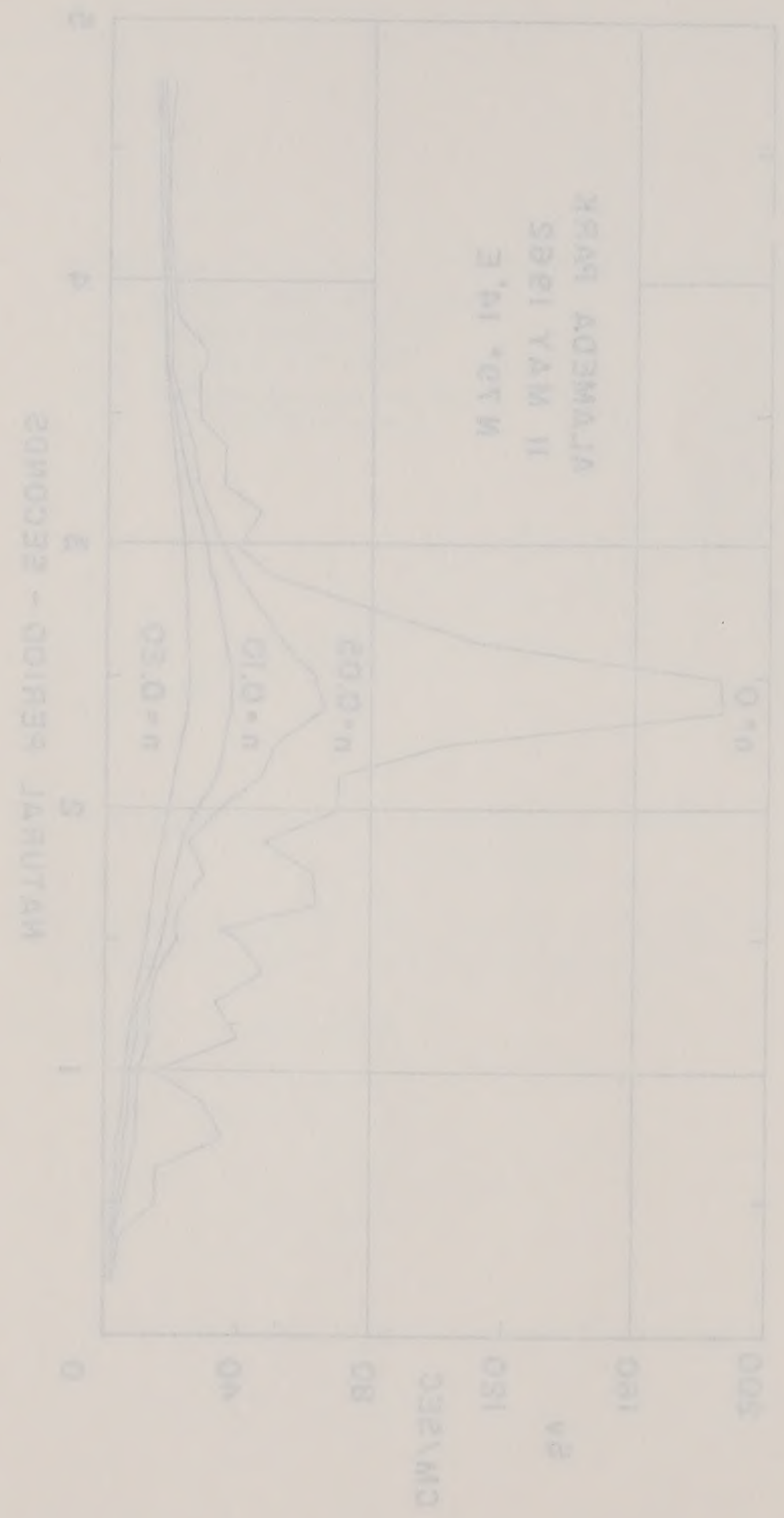


Figure 5. Velocity spectrum, 1962 earthquake near Mexico City.

(See "Mexican Earthquakes of 11 May and 19 May 1962,* by P. C. Jennings,
Earthquake Engineering Research Laboratory, C. I. T.)

The purpose of this study is to determine the effect of the concentration of the solution on the rate of the reaction. The results are shown in the table below.

Table 1. The effect of the concentration of the solution on the rate of the reaction.



The results of the study show that the rate of the reaction increases with the concentration of the solution. This is because a higher concentration of the solution means there are more reactant molecules available to undergo the reaction, leading to a faster rate.

1. The owner or developer of a particular site should be responsible for, and should bear the cost of the evaluation of those hazards that can be evaluated on or in the near-vicinity of the site.
2. Those hazards that cannot be adequately evaluated at the site should be considered for evaluation with public funds. The nature of the funding may vary depending on the extent of the impact of the hazard.
3. To facilitate the administration of public safety, it may be desirable to undertake, with public funds, a general evaluation of site-related hazards as they exist within an entire jurisdiction.

The application of these guidelines to geologic/seismic hazards depends on the type of hazard and the availability of information that can be used to evaluate the hazard. For example, faults can be located on a particular site by the engineering geologist during the site investigation. However, the rock formations necessary for evaluation of the activity of the fault are normally present only at certain critical locations, and evaluation of activity may require a publicly funded investigation. On the other hand, landslides can normally be evaluated as part of the site investigation funded by the owner or developer. Public agencies may wish to fund a general investigation of landslide hazards to facilitate the administration of public safety, but the final evaluation must be a part of site evaluation because additional hazard may be introduced by proposed modification of the site.

The distribution of emphasis of this Seismic Safety Element is based on these concepts. Those aspects of a particular hazard that cannot be evaluated on a site-basis, or which can more effeciently be evaluated on a regional basis, are emphasized in this analysis. Those hazards that can be effectively evaluated as a part of site investigations are treated in a general way with the intent that the results be used to facilitate the administration of public safety. It should be emphasized that such generalized evaluations should in no way be considered a substitute for a detailed site investigation which must consider not only existing conditions but also any hazards that may result from proposed modifications of the site.

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A key step in hazard evaluation is public involvement, through their elected representatives, in the determination of acceptable levels of risk. All hazards involve risk. A technical evaluation may determine certain risk parameters, but only the public can determine the acceptable balance between the risk of a hazard and the cost of mitigation. Because of the extreme importance of this step, primary emphasis is placed on the technical evaluation of available information relating to the risk of seismic hazards. The technical analysis can provide such information, but only the public sector can make the final determination of the acceptability of those risks.

The relationship between the concepts discussed above and the evaluation of specific seismic/geologic hazards is shown in Table 2. The primary responsibility for evaluation of each aspect of a hazard is shown by an "XX", and by a "XXX" if a determination of acceptable risk is involved. Those aspects for which either sector may commonly have a secondary responsibility are indicated by an "X". The intent is to show the distribution of responsibility for evaluation of a hazard; the overall regulatory responsibility of government is not included.

TABLE 2. DISTRIBUTION OF RESPONSIBILITY FOR
EVALUATION OF SEISMIC/GEOLOGIC HAZARDS

Hazard	Responsible Sector	
	Public	Private
1. Fault rupture:		
a. Evaluation of fault	XXX	
b. Location at site		XX
2. Earthquake shaking:		
a. Sources of shaking	XXX	
b. General levels of shaking	XX	X
c. Effects on site		XX
3. Tsunamic and seiche:		
a. Risk of occurrence	XXX	
b. Effects on site		XX
4. Dam failure:		
a. Risk of occurrence	XXX	
b. Effects on site		XX
5. Landslide:		
a. Regional evaluation	XX	X
b. Effects on site		XX
6. Liquefaction, settlement, & subsidence:		
a. Regional evaluation	XX ⁽¹⁾	
b. Effects on site		XX

X Secondary responsibility

XX Primary responsibility

XXX Primary responsibility including determination of
acceptable risk

(1) Evaluation requires determination of expected shaking.

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Hazard	Responsible Sector	
	Federal	Private
1. Fault rupture: a. Evaluation of fault; b. Location at site	XXX	XX
2. Earthquake shaking: a. Sources of shaking; b. General levels of shaking; c. Effects on site	XXX XX	X XX
3. Landslide and debris: a. Risk of occurrence; b. Effects on site	XXX	XX
4. Dam failure: a. Risk of occurrence; b. Effects on site	XXX	XX
5. Landslide: a. Regional evaluation; b. Effects on site	XX	X XX
6. Tsunami, sediment, & subsidence: a. Regional evaluation; b. Effects on site	XX(1)	XX

X Secondary responsibility
 XX Primary responsibility
 XXX Primary responsibility including determination of acceptable risk
 (1) Evaluation requires determination of expected shaking

II ANALYSIS OF SEISMIC HAZARDS

A. GEOLOGIC SETTING

The City of Burbank is located in the eastern San Fernando Valley. The central and southern parts of the City are underlain by the relatively soft alluvium of the valley, while the northern part of the City is underlain by the hard granitic and metamorphic rocks of the Verdugo Mountains. The areal distribution of these very different materials is shown on the geologic index map, Figure 6, and the vertical relationships are shown on the generalized geologic cross section, Figure 7.

The higher elevation of the Verdugo Mountains as related to the Valley is generally attributed to movement on the Verdugo fault (Wentworth and Yerkes, 1971). The fault is well exposed along the base of the mountains to the southeast in Glendale, but is generally buried under alluvium within the City of Burbank. Evidence bearing on the recency of movement of this fault is discussed in detail later in this report.

Other major faults bearing on the seismicity of the Burbank area are listed in Table 3 with their distance to the City, the maximum probable earthquakes expected and the resulting ground accelerations at Burbank, and the approximate probability of occurrence. Of the faults listed, the most significant as sources of earthquakes that could affect Burbank are the San Andreas because of its large magnitude and high probability of occurrence, and the frontal fault system of the San Gabriel Mountains because of its proximity and expected high ground accelerations. These faults and earthquakes that can be expected from them will be discussed in detail later in this report. Other faults in the area, with the exception of the Verdugo fault, are considered as being a lesser hazard either from the standpoint of lower expected ground acceleration or a lower probability of occurrence.

Seismic activity in the Los Angeles area is shown on Figures 8 and 9. The former shows the distribution of earthquakes from 1932 through 1949, while the latter shows the same type of data for the interval 1950 through 1970. Concentrations of epicenters are present along the Newport-Inglewood fault zone (Inglewood on map) and near the San Andreas at the eastern boundary of the map area. The area in and around Burbank is relatively "quiet" seismically. Figure 10 shows essentially the same data, all events for the period 1932 through 1972, but at a scale of 1" = 4 miles (1:250,000) which is the

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Figure 6. Geologic index map.

from Jennings and Strand, 1969.

TABLE 3. MAJOR FAULTS IN THE BURBANK AREA AND THEIR EXPECTED EFFECT ON THE CITY

SW	Distance from Burbank (mi.) (North-South)	Expected Magnitude (Richter)	Maximum Acceleration on "Firm Ground" (Grenvi)	NE
1. San Fernando Santa Monica Mountains	4-8	6.5	0.17-0.33	Verdugo Mountains
2. San Gabriel San Gabriel Mtns.	8-7	6.6	0.33-0.48	Low
3. San Andreas	11-12	6.9	0.33-0.35	Intermediate
4. Newport-Inglewood				

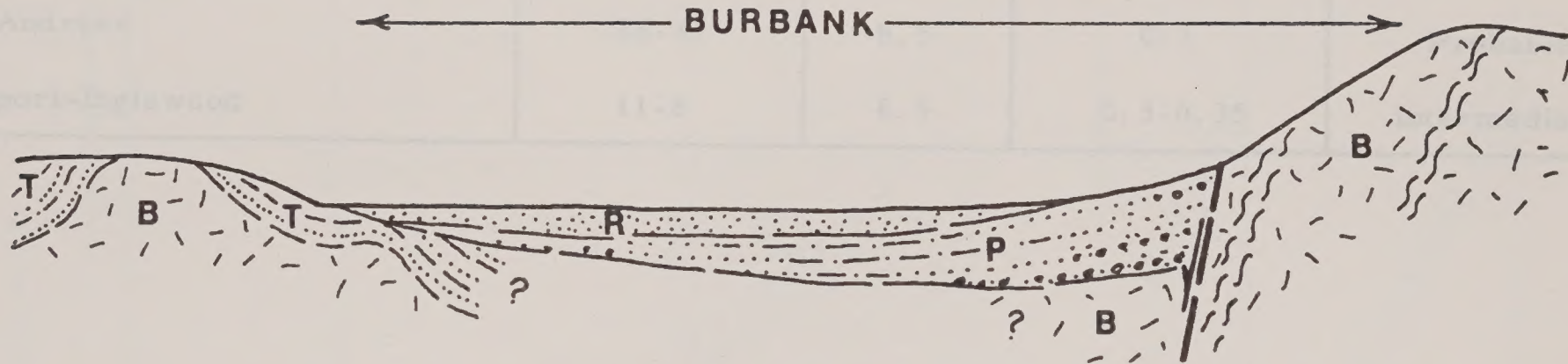


Figure 7. Diagrammatic geologic cross section. R = Recent alluvium; P = Pleistocene alluvium; T = Tertiary sedimentary rocks; and B = Basement rocks.

TABLE 3. MAJOR FAULTS IN THE BURBANK AREA AND THEIR EXPECTED EFFECT ON THE CITY

	Distance from Burbank (Mi.) (North-South)	Expected Magnitude (Richter)	Maximum Acceleration on "Firm Ground" (Gravity)	Approximate Probability of Occurrence (100-year Period)
1. San Fernando	5-9	6.6	0.47-0.33	Low
2. Frontal fault of San Gabriel Mtns.	4-7	6.6	0.53-0.40	Intermediate
3. San Andreas	28-31	8.5	0.3	Probable
4. Newport-Inglewood	11-8	6.5	0.3-0.35	Intermediate

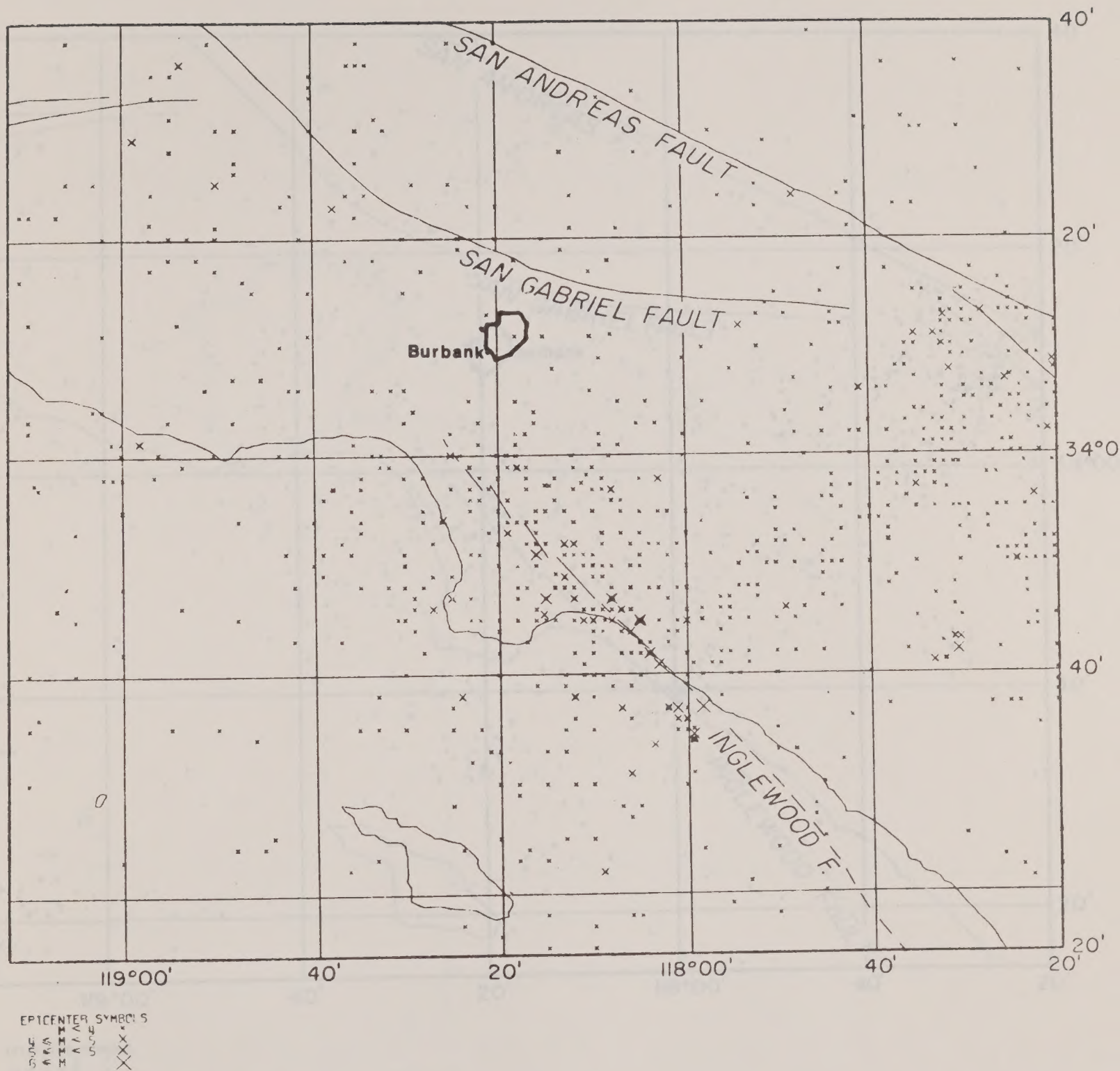


Figure 8. Earthquake epicenters in the Los Angeles area, 1932 through 1949.

from Hileman et al, 1973.

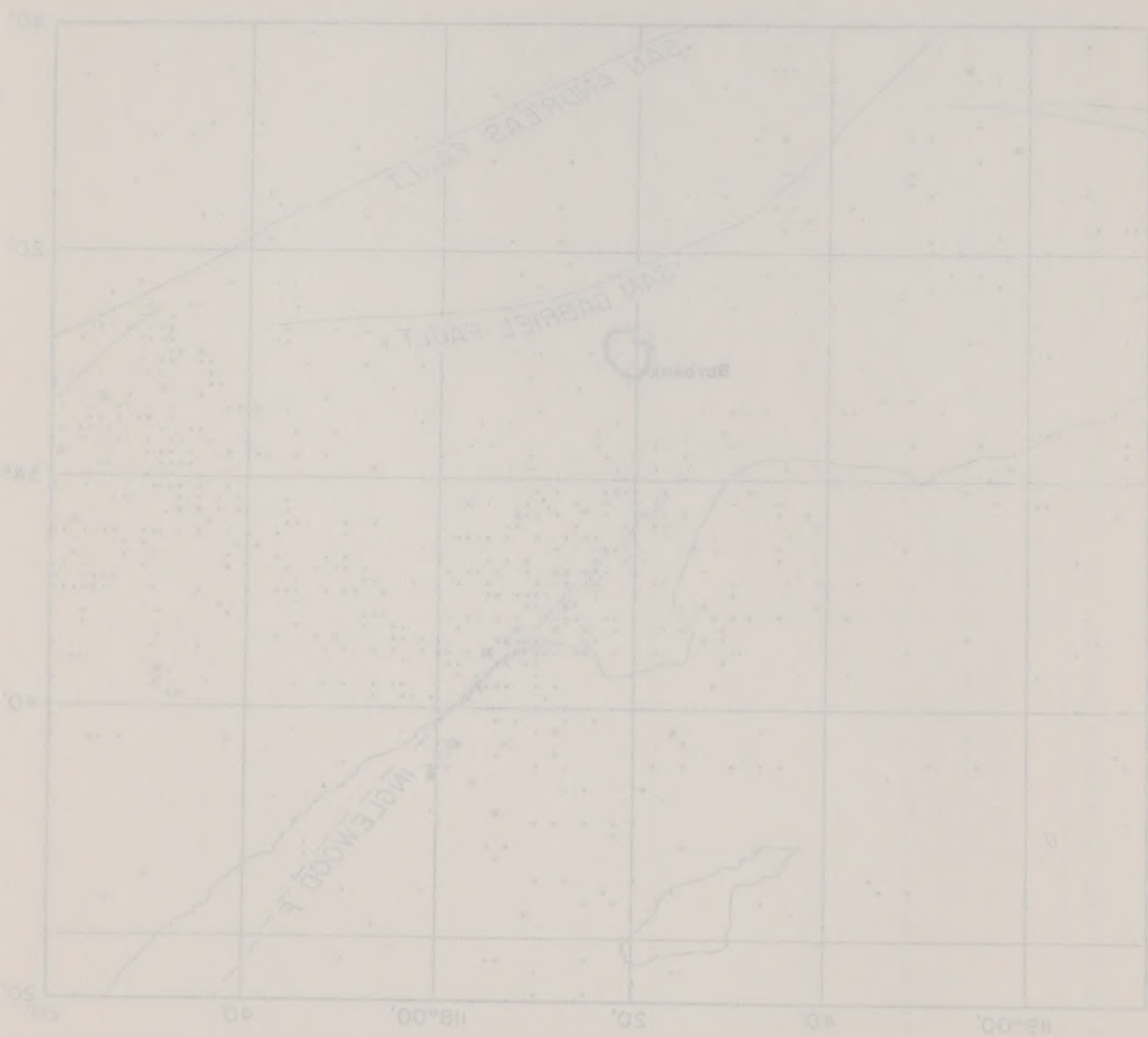
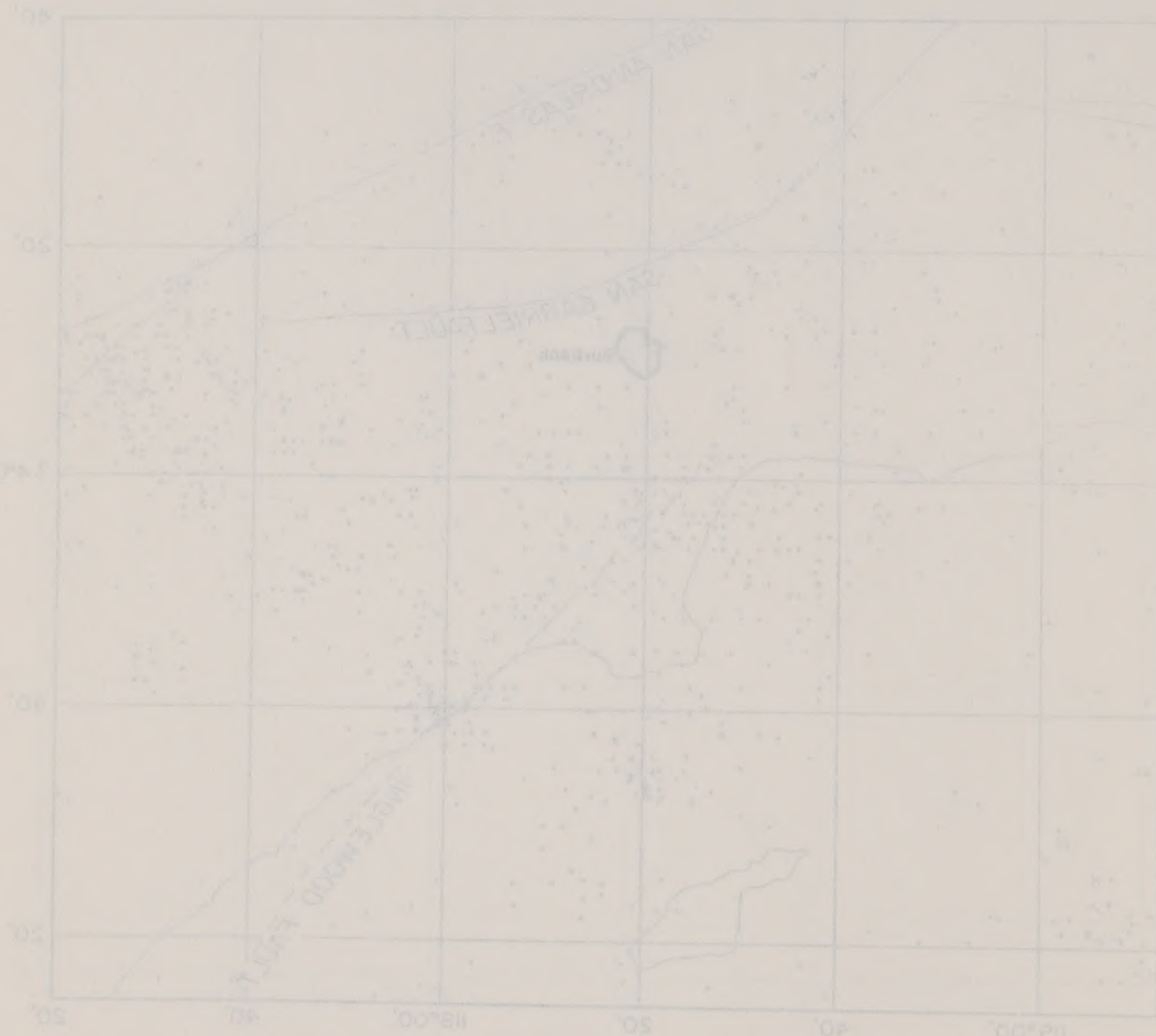


Figure 8. Earthquake epicenters in the Los Angeles area, 1915 through 1949.

from Hileman et al., 1973.

Figure 2. Earthquake epicenters in the Los Angeles area, 1950 through 1970.
 from Housen et al, 1973.

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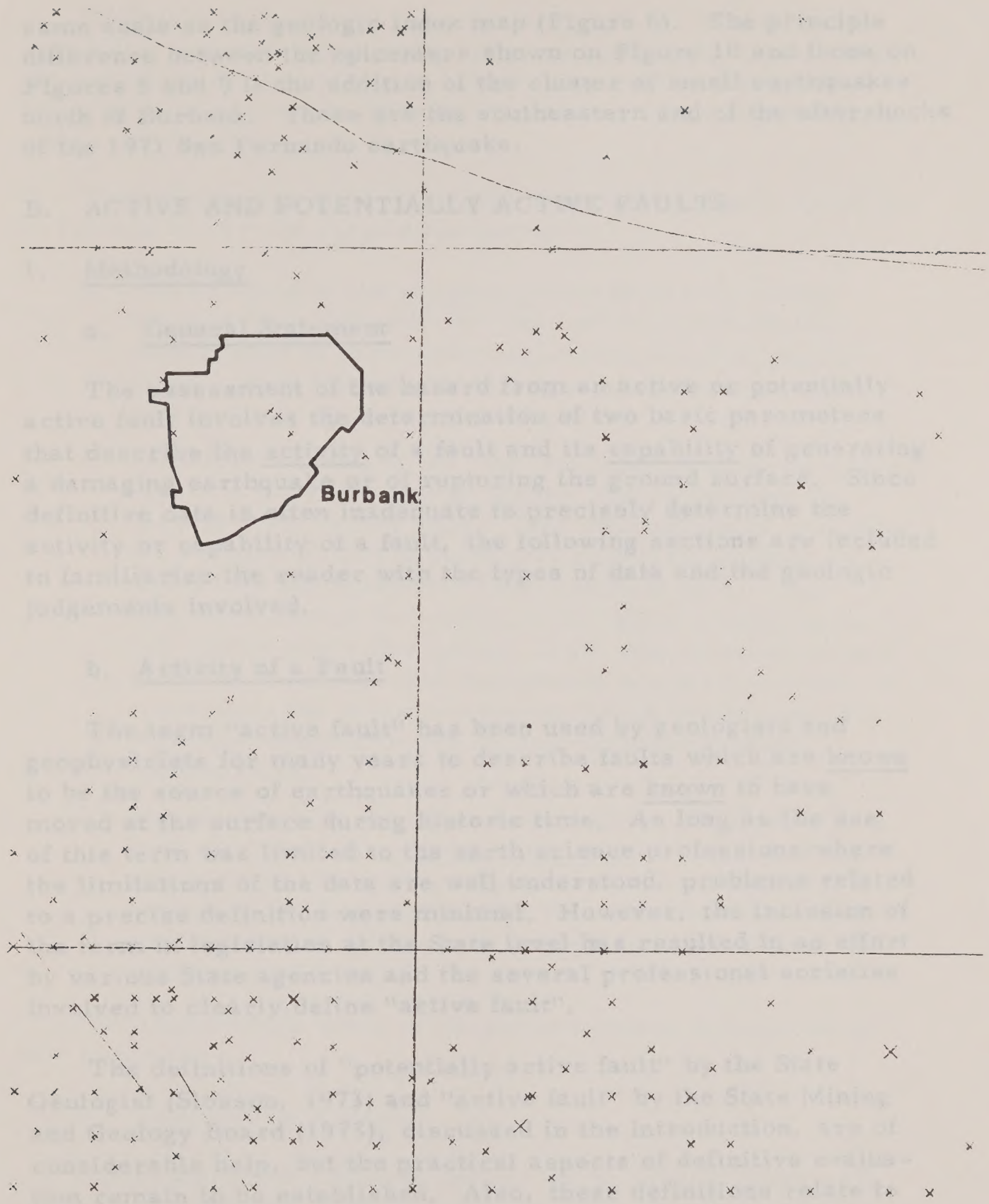


Figure 10. Earthquake epicenters in the Burbank area, 1932 through 1972.



Figure 10. Euphorbia esula in the Burbank area, 1935 through 1975.

same scale as the geologic index map (Figure 6). The principle difference between the epicenters shown on Figure 10 and those on Figures 8 and 9 is the addition of the cluster of small earthquakes north of Burbank. These are the southeastern end of the aftershocks of the 1971 San Fernando earthquake.

B. ACTIVE AND POTENTIALLY ACTIVE FAULTS

1. Methodology

a. General Statement

The assessment of the hazard from an active or potentially active fault involves the determination of two basic parameters that describe the activity of a fault and its capability of generating a damaging earthquake or of rupturing the ground surface. Since definitive data is often inadequate to precisely determine the activity or capability of a fault, the following sections are included to familiarize the reader with the types of data and the geologic judgements involved.

b. Activity of a Fault

The term "active fault" has been used by geologists and geophysicists for many years to describe faults which are known to be the source of earthquakes or which are known to have moved at the surface during historic time. As long as the use of this term was limited to the earth science professions where the limitations of the data are well understood, problems related to a precise definition were minimal. However, the inclusion of the term in legislation at the State level has resulted in an effort by various State agencies and the several professional societies involved to clearly define "active fault".

The definitions of "potentially active fault" by the State Geologist (Slosson, 1973) and "active fault" by the State Mining and Geology Board (1973), discussed in the Introduction, are of considerable help, but the practical aspects of definitive evaluation remain to be established. Also, these definitions relate to activity as determined by, and as applied to, the hazard of fault rupture. Activity as may be suggested by earthquake epicenter locations is not defined, and the relationship between evaluations within the Special Studies Zones and the more general hazard of earthquake shaking is as yet unclear.

same scale as the geologic index map (Figure 5). The difference between the epicenters shown on Figure 10 and those on Figures 8 and 9 is the addition of the cluster of small earthquakes north of Bismarck. These are the southeastern end of the aftershock of the 1971 San Fernando earthquake.

B. ACTIVE AND POTENTIALLY ACTIVE FAULTS

1. Methodology

a. General Statement

The assessment of the hazard from an active or potentially active fault involves the determination of two basic parameters that describe the activity of a fault and its capability of generating a damaging earthquake or of rupturing the ground surface. Since definitive data is often inadequate to precisely determine the activity or capability of a fault, the following sections are included to illustrate the reader with the types of data and the geologic judgments involved.

b. Activity of a Fault

The term "active fault" has been used by geologists and geophysicists for many years to describe faults which are known to be the source of earthquakes or which are known to have moved at the surface during historic time. As long as the use of this term was limited to the earth science professions where the limitations of the data are well understood, geologists related to a precise definition were minimal. However, the inclusion of the term in legislation at the State level has resulted in an effort by various State agencies and the several professional societies involved to clearly define "active fault".

The definition of "potentially active fault" by the State Geologist (Johnson, 1973) and "active fault" by the State Mining and Geology Board (1973), discussed in the Introduction, are of considerable help, but the practical aspects of definitive evaluation remain to be established. Also, these definitions relate to activity as determined by, and as applied to, the hazard of fault rupture. Activity as may be suggested by earthquake epicenters locations is not defined, and the relationship between evaluation within the Special Studies Zones and the more general hazard of earthquake shaking is as yet unclear.

While a high degree of conservatism may be feasible in the regulation of construction along active or potentially active faults, the use of the same criteria in establishing codes relating to hazards from earthquake shaking may have profound economic and social impacts.

The activity of a fault is related to recurrence rate which can be derived in at least three different ways:

1. The analysis of the seismicity of a fault may reveal relationships that indicate that, at least statistically, earthquakes of particular magnitudes recur at regular rates. Data suitable for this type of analysis is available for only about the last 40 years.
2. The measurement of the movement of the earth on either side of a fault, or crustal strain, can sometimes be derived from survey data. This information is available for a longer period of time, but movement is often so small it is not detectable from ordinary data. Very accurate surveys have been conducted in recent years, but across only a few faults. If the rate of accumulation of strain is known, then the amount of time necessary to accumulate the strain necessary for an earthquake of a particular magnitude can be estimated from other relationships.
3. The relationship of unique rock units on either side of a fault may yield the geologic slip rate if the ages of the unique units are known. The principal problem with this method is the assumption that rates obtained for a time span of several million, or several tens of millions of years are valid today.

The applicability of any of the above methods depends on the data available.

c. Capability of a Fault

The capability of a fault is defined as the largest earthquake, in Richter magnitude, that the fault will probably generate if it should move. If a fault has moved during that part of the recent past for which magnitude data are available, the capability of that fault can be estimated from the historic record. However, if the

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1. The analysis of the seismicity of a fault may reveal relationships that indicate that, at least statistically, earthquakes of particular magnitudes recur at regular rates. This statistic for this type of analysis is available for only about the last 40 years.
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3. The relationship of active rock units on either side of a fault may yield the geologic slip rate if the ages of the rock units are known. The principal problem with this method is the assumption that rates obtained for a time span of several million, or several tens of millions of years are valid today.

The applicability of any of the above methods depends on the data available.

Capacity of a Fault

The capacity of a fault is defined as the largest earthquake in history magnitude, that the fault will probably generate if it should move. If a fault has moved during that part of the recent past for which magnitude data are available, the capacity of that fault can be estimated from the historic record. However, if the

activity of a fault is low, it may not have generated the largest earthquake of which it is capable during that time for which instrumental data are available. The capability of these faults can be estimated from their physical dimensions.

Data on the movements of faults and the magnitudes of the resulting earthquakes have been compiled by Bonilla and Buchanan (1970) from worldwide sources. Their analysis of this data indicates that there are empirical relationships between the length of surface rupture and the magnitude of the resulting earthquake, depending on the type of movement. Simply stated, the longer the fault, the larger the earthquake; but the exact relationship depends also on the type of movement.

Fault movement can be divided into three basic types illustrated in Figure 11. The type most commonly associated with recent activity is strike-slip movement because it is the dominant movement occurring on the San Andreas fault. It is characterized by horizontal slip of the two adjacent blocks relative to each other, with the dominant direction of movement being parallel to the trend of the fault. The alternative to strike-slip movement is dip-slip, or up-down, movement. Faults of this type, however, should be separated into those that result from a pulling-apart or tensional movement, and those that result from a pushing-together or compressional movement. The former are called normal faults, and the latter are called reverse faults.

The relationships between length of rupture and earthquake magnitude for strike-slip and for normal faults are shown on Figure 12. Data is at present inadequate to define a difference in the relationship between normal and reverse faults, but the theory as to the forces involved suggests reverse faults should generate larger magnitudes for comparable lengths of rupture.

The discussion above is for recent fault breaks that can be identified on the ground after the earthquake. The evaluation of a fault's capacity to generate an earthquake, based on data other than earthquakes that it is known to have generated, involves an estimate of the length of the segment expected to move and the type of movement most likely to occur. This requires that the length of the fault be determined, and then that the extent of individual segments of the fault most likely to rupture at one time be determined. This process is very subjective, and

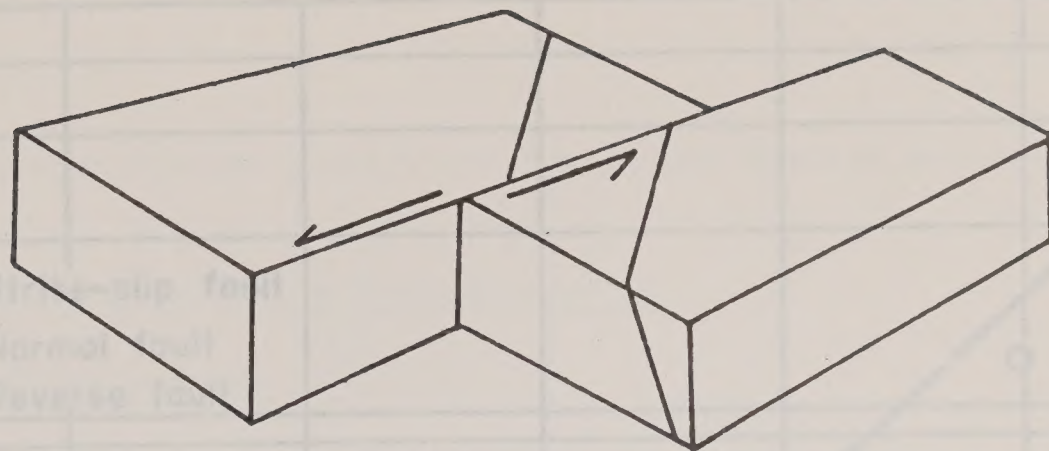
activity of a fault is low, it may not have generated the largest earthquake of which it is capable during that time for which instrumental data are available. The capability of these faults can be estimated from their physical dimensions.

Data on the movements of faults and the magnitudes of the resulting earthquakes have been compiled by Bouffé and Buchanan (1970) from worldwide sources. Their analysis of this data indicates that there are empirical relationships between the length of surface rupture and the magnitude of the resulting earthquake, depending on the type of movement. Simply stated, the larger the fault, the larger the earthquake; but the exact relationship depends also on the type of movement.

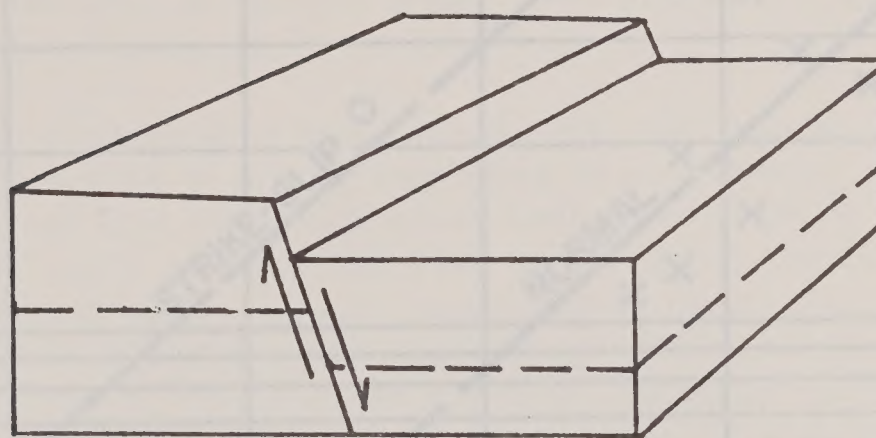
Fault movement can be divided into three basic types illustrated in Figure 11. The type most commonly associated with recent activity is strike-slip movement because it is the dominant movement occurring on the San Andreas fault. It is characterized by horizontal slip of the two adjacent blocks relative to each other, with the dominant direction of movement being parallel to the trend of the fault. The alternative to strike-slip movement is dip-slip, or up-down, movement. Faults of this type, however, should be separated into those that result from a pulling-apart or tensional movement, and those that result from a pushing-together or compressional movement. The former are called normal faults, and the latter are called reverse faults.

The relationships between length of rupture and earthquake magnitude for strike-slip and for normal faults are shown on Figure 12. Data is at present inadequate to define a difference in the relationship between normal and reverse faults, but the theory as to the forces involved suggests reverse faults should generate larger magnitudes for comparable lengths of rupture.

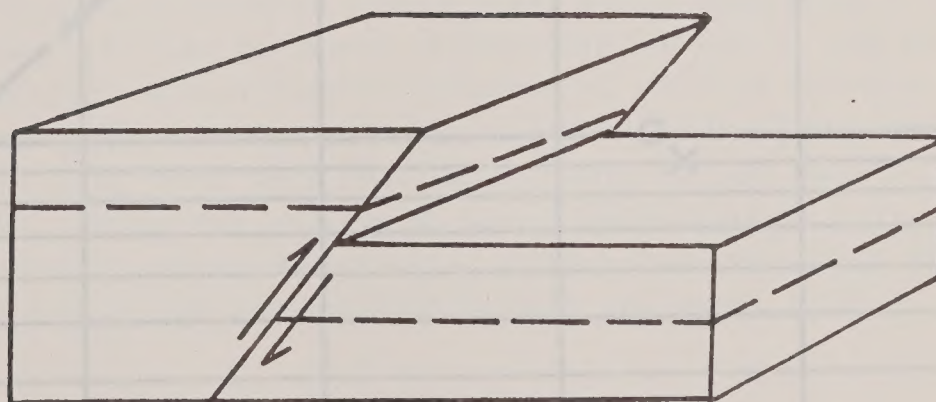
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Strike-slip or lateral fault



Normal (dip-slip) fault



Reverse (dip-slip) fault

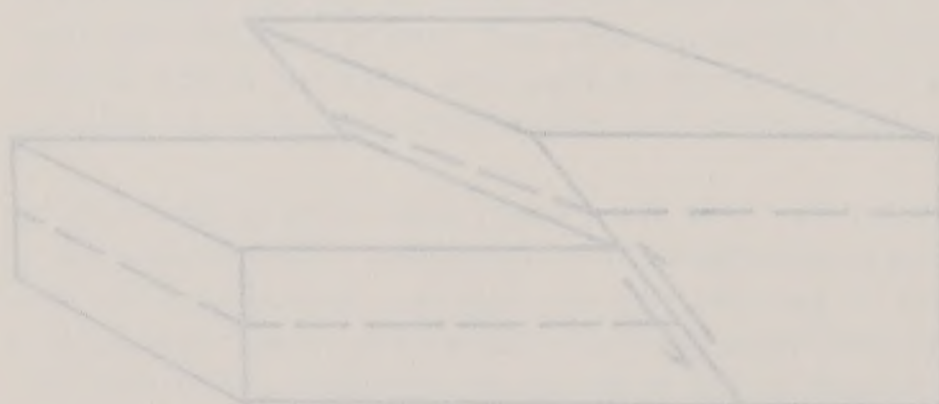
Figure 11. Types of fault movement.



Strike-slip or lateral fault



Normal (dip-slip) fault



Reverse (dip-slip) fault

Figure 11. Types of fault movement.

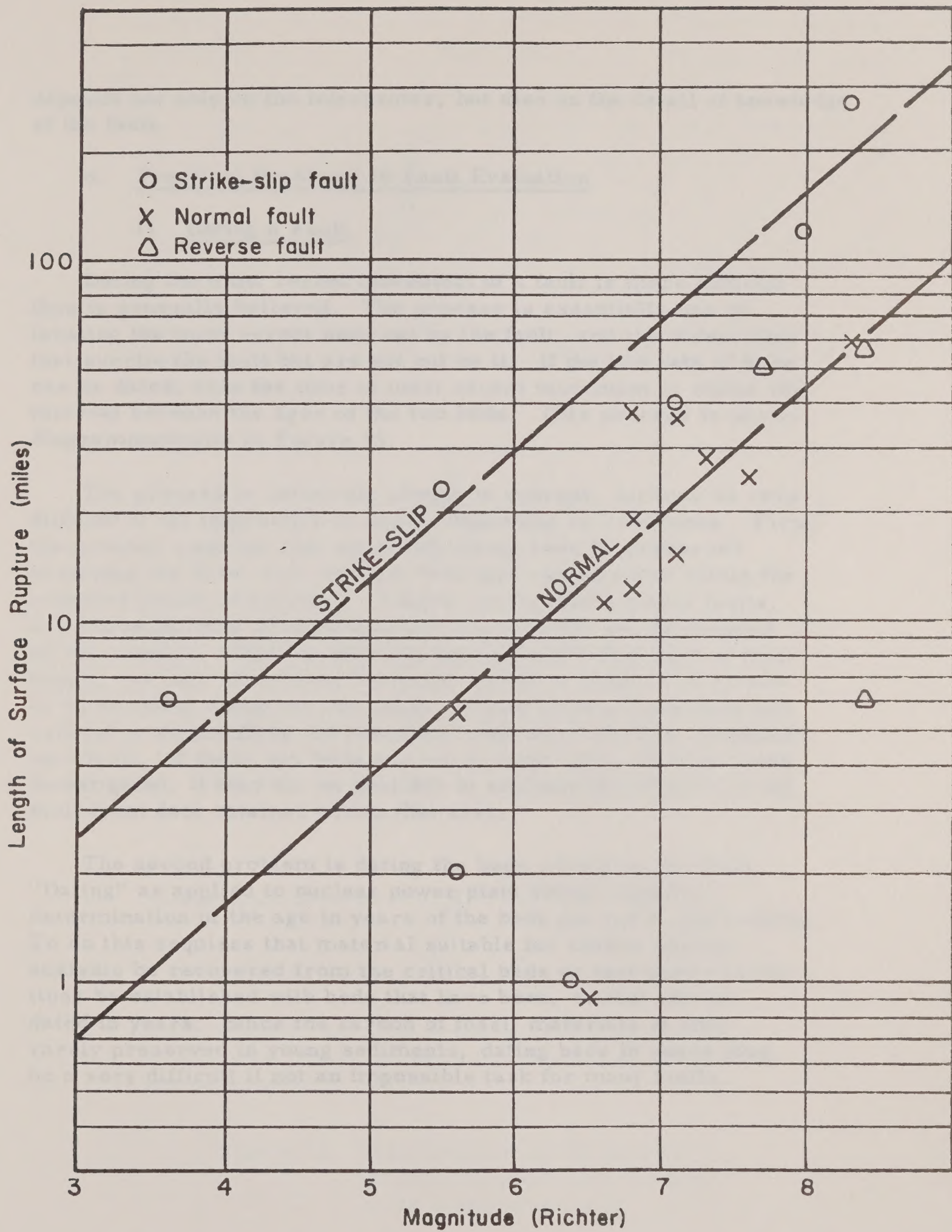
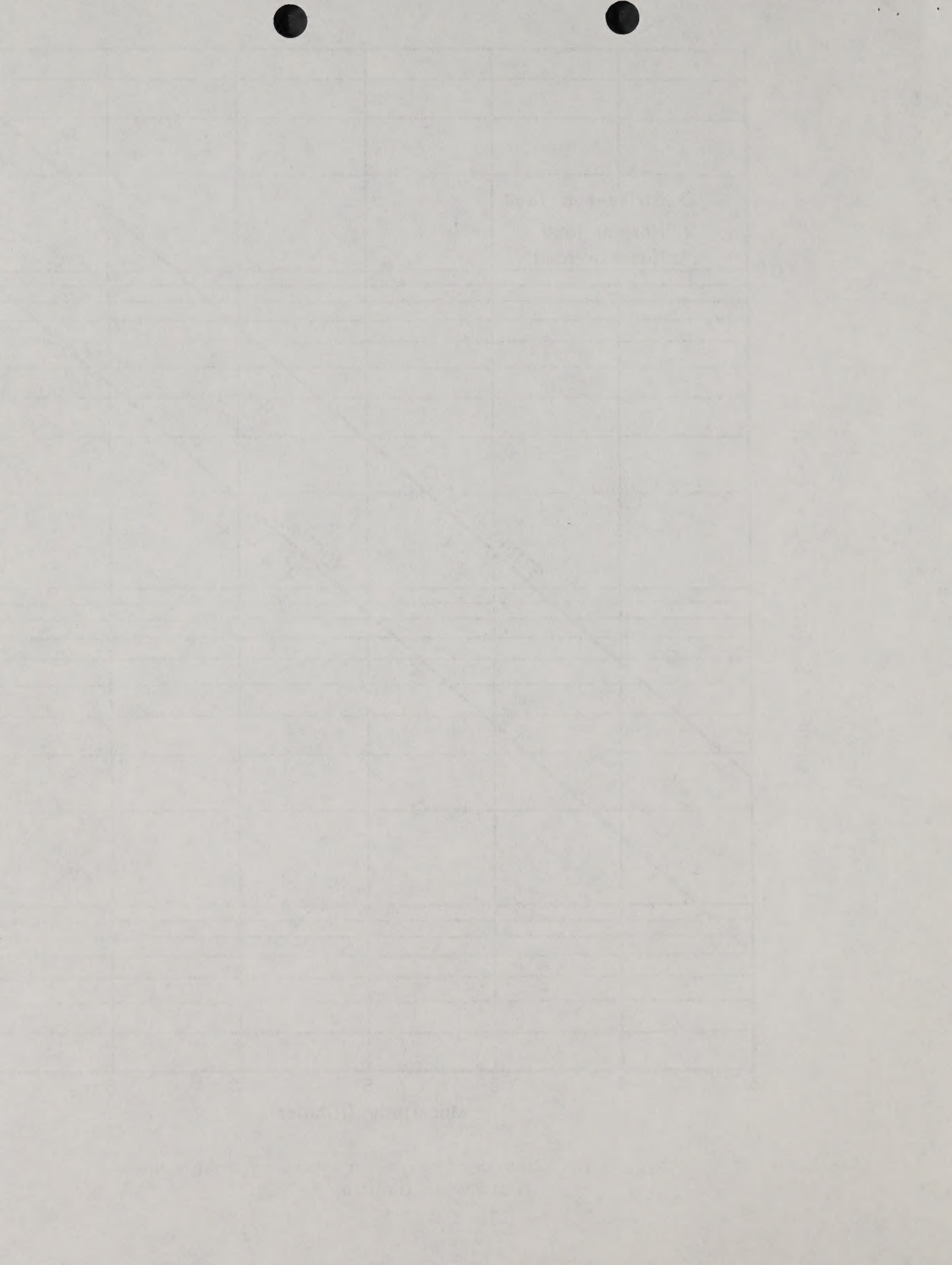


Figure 12. Length of surface rupture vs. magnitude.
Data from Bonilla, 1970.



depends not only on the interpreter, but also on the detail of knowledge of the fault.

d. Practical Problems in Fault Evaluation

1) Dating a Fault

Dating the most recent movement of a fault is more difficult than is generally believed. The process is essentially one of locating the most recent beds cut by the fault, and the oldest beds that overlie the fault but are not cut by it. If the two sets of beds can be dated, then the time of most recent movement is within the interval between the ages of the two beds. This process is shown diagrammatically in Figure 13.

The process is relatively simple in concept, but may be very difficult if not impossible to apply, depending on conditions. First, the process requires that relatively young beds be preserved overlying the fault; and, second, that they can be dated within the required limits of accuracy. Faults, particularly major faults, are known to exist because they are exposed and can be mapped on the surface. That is, they are not covered along most of their length, but only at isolated localities as along streams or rivers or by terraces along the sea coast. These isolated localities are critical to establishing the minimum time since the last movement on a fault. If these key beds are not present within an area being investigated, it may not be possible to evaluate the activity of the fault from data obtained within that area.

The second problem is dating the beds overlying the fault. "Dating" as applied to nuclear power plant siting requires a determination of the age in years of the beds not cut by the faulting. To do this requires that material suitable for carbon isotope analysis be recovered from the critical beds or that good correlations be established with beds that have been, or that can be, dated in years. Since the carbon of fossil materials is only rarely preserved in young sediments, dating beds in years may be a very difficult if not an impossible task for many faults.

Figure 13. Diagrammatic cross section illustrating conditions related to the dating of a fault.

depends not only on the interpreter, but also on the detail of knowledge of the fault.

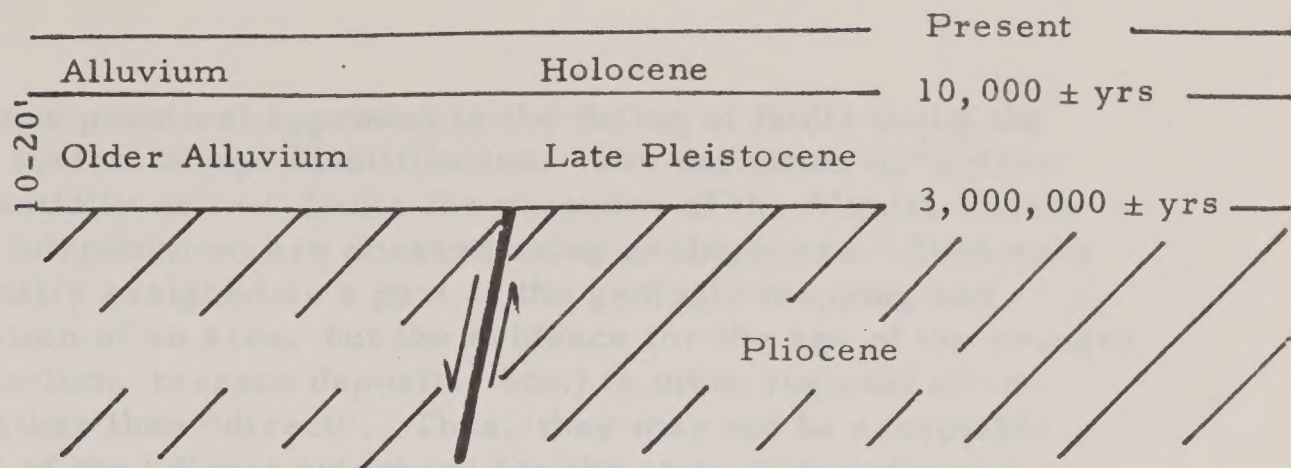
4. Practical Problems in Fault Evaluation

1) Dating a Fault

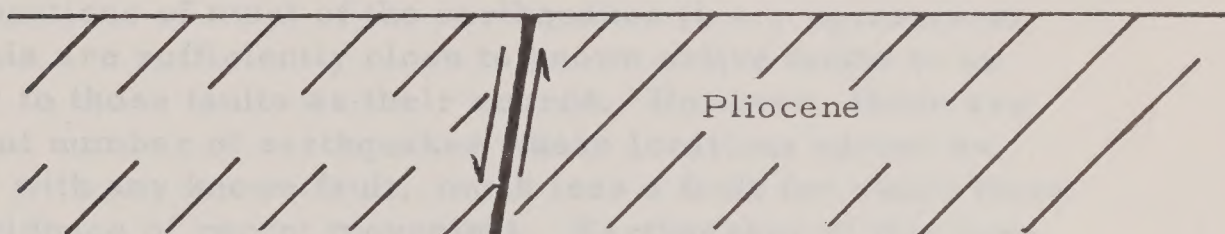
Dating the most recent movement of a fault is more difficult than is generally believed. The process is essentially one of locating the most recent beds cut by the fault, and the oldest beds that overlap the fault but are not cut by it. If the two sets of beds can be dated, then the time of most recent movement is within the interval between the ages of the two beds. This process is shown schematically in Figure 15.

The process is relatively simple in concept, but may be very difficult to apply, depending on conditions. First, the process requires that relatively young beds be preserved overlying the fault, and, second, that they can be dated within the required limits of accuracy. Faults, particularly major faults, are known to exist because they are exposed and can be mapped on the surface. That is, they are not covered along most of their length, but only at isolated localities as along streams or rivers or by terraces along the sea coast. These isolated localities are critical to establishing the minimum time since the last movement on a fault. If these few beds are not preserved within an area being investigated, it may not be possible to establish the activity of the fault from data obtained within that area.

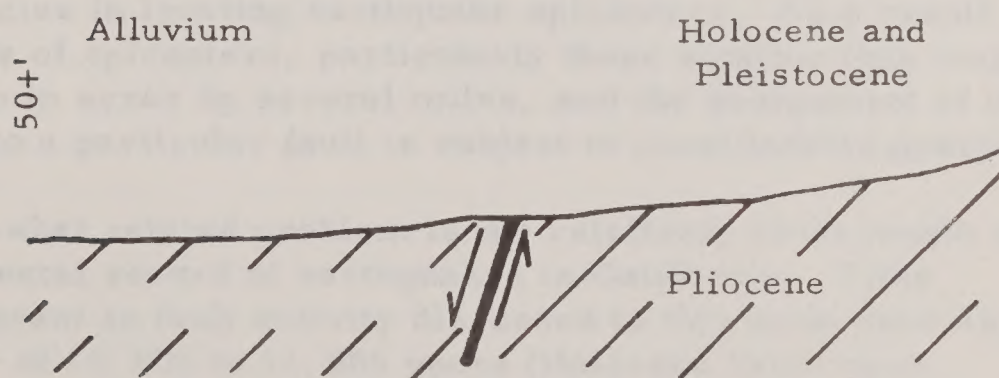
The second problem in dating the beds overlying the fault, "Dating", as applied to nuclear power plant siting requires a determination of the age in years of the beds not cut by the faulting. To do this requires that material suitable for carbon isotopic analysis be recovered from the critical beds or that good correlations be established with beds that have been, or that can be, dated in years. Since the carbon of fossil materials is only rarely preserved in young sediments, dating beds in years may be a very difficult if not an impossible task for many faults.



Most recent movement on fault can be dated as post-Pliocene and pre-older alluvium; i. e. between 10,000 and 3,000,000 years ago.

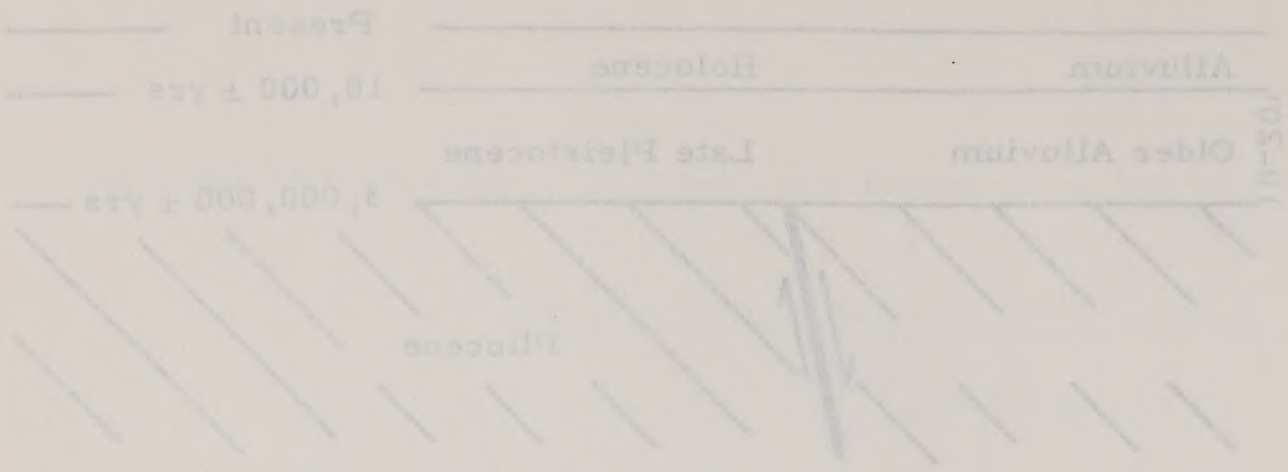


Fault is exposed at surface with no overlying unfaulted beds. Most recent movement cannot be established.



Fault is buried too deep to be exposed in exploratory trench, and cannot be dated unless shallower exposures can be located.

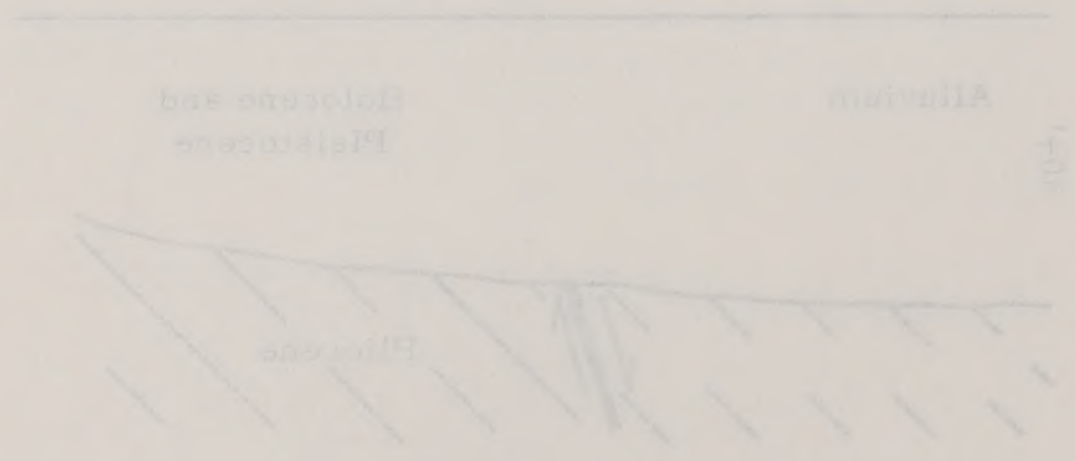
Figure 13. Diagrammatic cross section illustrating conditions related to the dating of a fault.



Most recent movement on fault can be dated as post-Pliocene and pre-older alluvium; i.e. between 10,000 and 1,000,000 years ago.



Point is exposed at surface with no overlying unstratified beds. Most recent movement cannot be established.



Fault is buried too deep to be exposed in exploratory trench, and cannot be dated unless shallow exposure can be located.

Figure 13. Diagrammatic cross section illustrating conditions related to the dating of a fault.

A more practical approach is the dating of faults using the geologic system of age identification. The definition of "active" and "potentially active" faults for purposes of the Alquist-Priolo Act (see Introduction) are phrased using geologic age. Such ages are normally assigned as a part of the geologic mapping and investigation of an area, but the evidence for the age of the younger beds (alluvium, terrace deposits, etc.) is often regional or inferred rather than "direct". Thus, they may not be acceptable as a part of the "direct evidence" for the state of activity of a fault as required by the State Geologist for Special Studies Zones established as required by the Alquist-Priolo Act.

2) Activity Based on Seismicity

The locations of most of the earthquakes (i. e., epicenters) in California are sufficiently close to known active faults to be "assigned" to those faults as their source. However, there are a significant number of earthquakes whose locations cannot be associated with any known fault, much less a fault for which there is other evidence of recent movement. Earthquakes of this type can be considered as a "background" of seismic activity that is composed primarily of smaller quakes (Richter magnitude 4 or less), but which also includes some in the range of 4 to 5.

The problem of separating this "background" of activity from that which should be assigned to particular faults is complicated by inaccuracies in locating earthquake epicenters. As a result, the locations of epicenters, particularly those smaller than magnitude 4.0, may be in error by several miles, and the assignment of most epicenters to a particular fault is subject to considerable question.

A somewhat related problem is the relatively short length of the instrumental record of earthquakes in California. Time periods relevant to fault activity discussed to this point have been of the order of 10,000 to 11,000 years (Holocene time) up to 3,000,000 years (Quaternary time). In contrast, the instrumental record is only about 40 years in length, with qualitative data for larger earthquakes (e. g., the 1857 Fort Tejon earthquake) extending back to the early 1800's. This record can be considered reasonably representative of a 100- or 200-year period, but is certainly inadequate for extrapolations of the order of thousands of years.

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e. Summary of Methodology

The potential hazard of a particular fault can be described in terms of its activity and capability. For purposes of comparing faults, activity is described in terms of the recurrence intervals for earthquakes of various magnitudes.

The capability of a fault to generate earthquakes is described in terms of the largest earthquake that it should be expected to generate (i. e., "maximum probable" earthquake). This determination is based on the length of the fault segment that is likely to move, and, because of the assumptions involved, is rather subjective particularly for faults with low levels of activity.

The activity and the capability of a fault should be considered in that order because the capability may be relatively unimportant if the activity level is low. The minimum level of activity that should be considered as constituting a hazard in any particular area is related to acceptable risk, and is, therefore, a matter of public policy. Also, the minimum level of activity that may be considered hazardous with respect to a fault as a source of earthquake shaking may differ from the minimum level for ground rupture. For these reasons, and because the various jurisdictions involved may wish to establish different levels of acceptable risk, the activity level and capability are derived for each of the major faults in the study area. However, it should be emphasized that a relatively high capability does not necessarily indicate a high level of hazard. Capability is important if activity exceeds minimum levels of acceptable risk. It is also of importance as an indicator of faults requiring particular attention, but it should not be considered by itself as an indication of hazard.

2. Verdugo Fault

a. Location

The Verdugo fault is located along the lower slopes of the Verdugo Mountains or in the alluvium just south of the Mountains (Plate I and Figure 7). It is generally considered as the main surface of movement along which the mountains have been raised to their present position approximately 3,000 feet above basement rocks in the valley to the south.

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The activity and the capability of a fault should be considered in that order because the capability may be relatively unique, but the activity level is low. The minimum level of activity that should be considered as constituting a hazard in any given location is related to acceptable risk, and is, therefore, a matter of public policy. Also, the minimum level of activity that may be considered hazardous with respect to a fault as a source of earthquakes might vary with the minimum level for ground motions. For these reasons, and because the various institutions involved may wish to establish different levels of acceptable risk, the activity level and capability are derived for each of the major faults in the study area. However, it should be emphasized that a relatively high capability does not necessarily indicate a high level of hazard. Capability is important if activity exceeds minimum levels of acceptable risk. It is also of importance as an indicator of faults requiring particular attention, but it should not be considered by itself as an indicator of hazard.

5. Verdugo Fault

a. Location

The Verdugo fault is located along the lower slopes of the Verdugo Mountains at its northern end south of the Mojave Desert (Plate 1 and Figure 1). It is generally considered as the main source of movement along which the mountains have been raised in their present position approximately 3,000 feet above basement rocks in the valley to the south.

The fault has been mapped on the surface in northeastern Glendale and at scattered location in Burbank. The report of the California State Water Rights Board (1962), Volume II, Appendix A, states:

"It is plainly exposed on either side of a ravine (north of Burbank) for 50 to 75 feet; it dips 70 degrees south. Older reddish brown consolidated Quaternary gravelly sand is sharply down faulted against Basement Complex. Brecciation, gouge and calcitic vein material all occur in the fault. This fault extends under the alluvium along a line extending along the southern foot of the Verdugo Hills to the south of the Pacoima Hills, an outlier of the Verdugo block."

This exposure of the fault could not be located during our field reconnaissance, but an excellent exposure was located in the cut for an unbuilt-on lot pad at the north end of Church's Court (Figure 14 and Plate I). This exposure is consistent with a report by Dr. Perry Ehlig (personal communication) of basement rocks faulted against terrace gravels exposed in an excavation for the golf course in Stough Canyon.

Reports of the rupture of relatively young rocks are also reported in the Pacoima Hills to the northwest and in Verdugo Canyon to the southeast (California State Water Rights Board, 1962). The exposures in the Pacoima Hills involve clayey gouge seams in sands and gravels, while the evidence in Verdugo Canyon is a buried groundwater cascade "controlled by offsets in bedrock along the Verdugo fault zone".

The location of the Verdugo fault is "keyed" to exposures of the fault described above, but its location along most of its length is based on projections of the observed trend and on the gravity data of Corbato (1960). The latter defined a gravity "high" that trends approximately parallel to the fault and located about 1500 feet to the north of the exposed or buried trace of the fault. One significant departure from this relationship is the bending of the fault into Stough Canyon as established by the exposure on Church's Court and the outcrops of basement rocks of the mountain block to the northwest of Stough Canyon. These relationships require a sharp bend in the trend of the fault at Stough Canyon, or the offsetting of the fault by a fault in the Canyon. The latter is considered the more likely although the evidence is not conclusive. The gravity data shows a change in trend at the Canyon, but this type of data is too general to establish precise relationships. The zone within which the trace of the fault is present, either at the surface or buried beneath alluvium, is shown on Plate I as Zone VA.

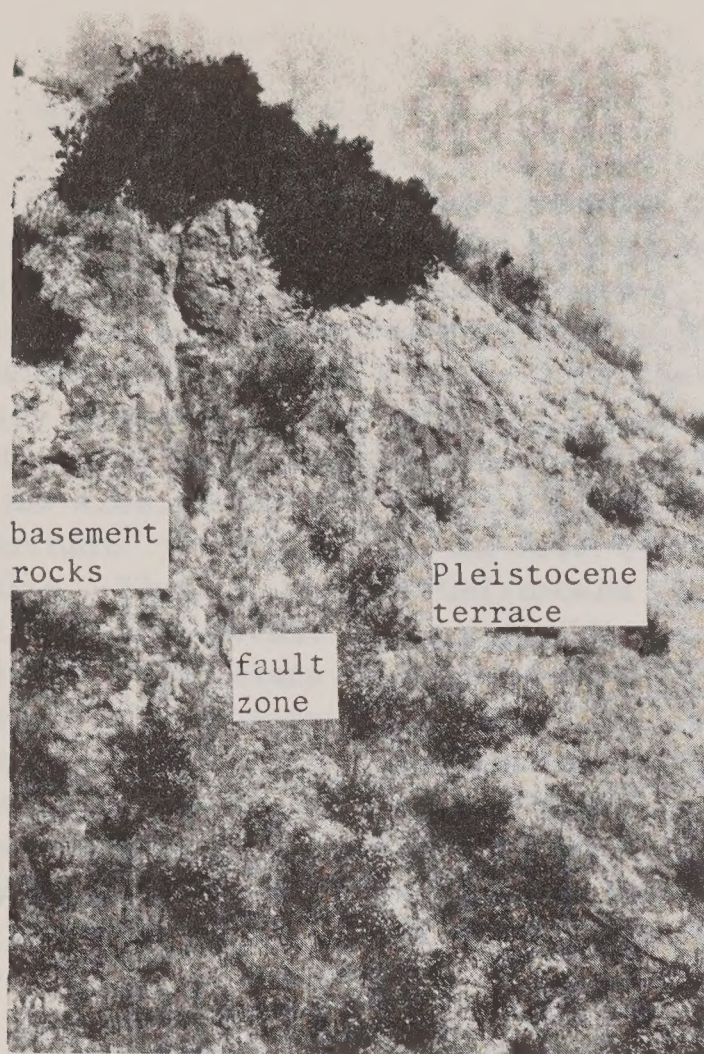
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View looking east shown at left. Below is close-up of fault zone from near top of view at left.

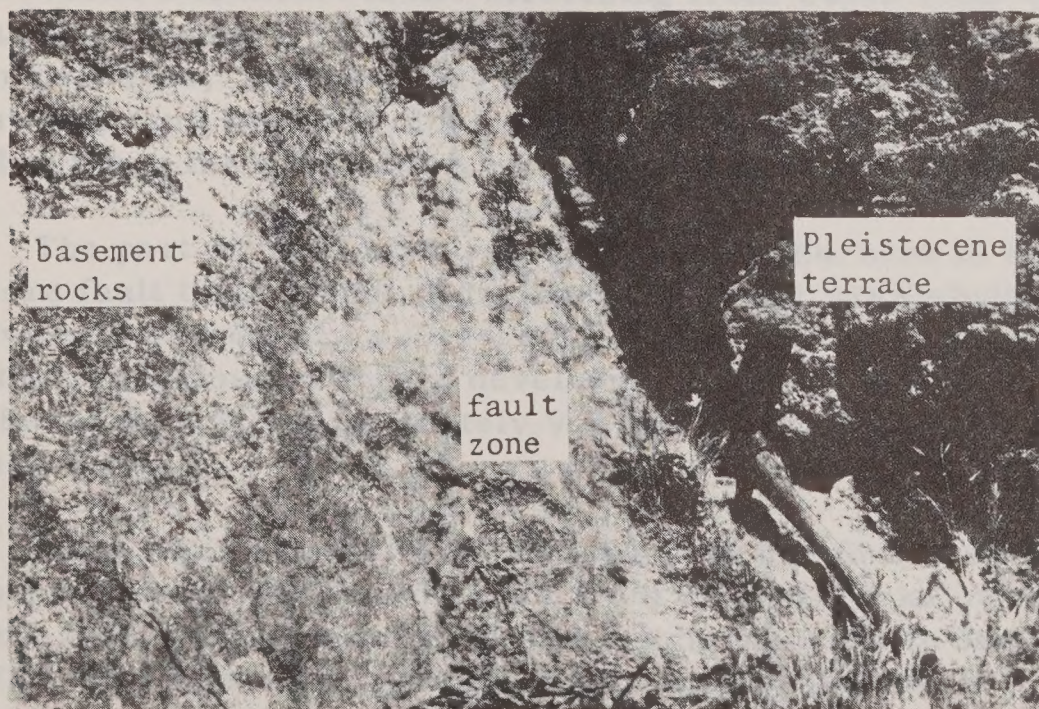


Figure 14. Views of Verdugo fault exposed at north end of Church's Court.

View looking east shows
at left. Below is
cross-section of fault zone
from near top of view
at left.

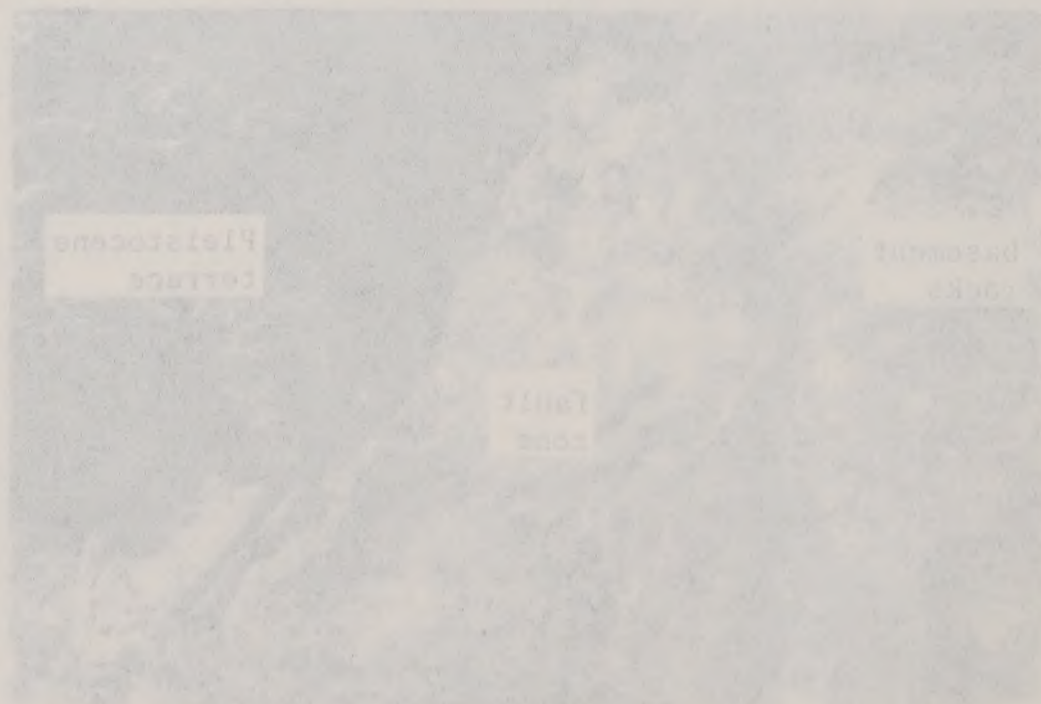
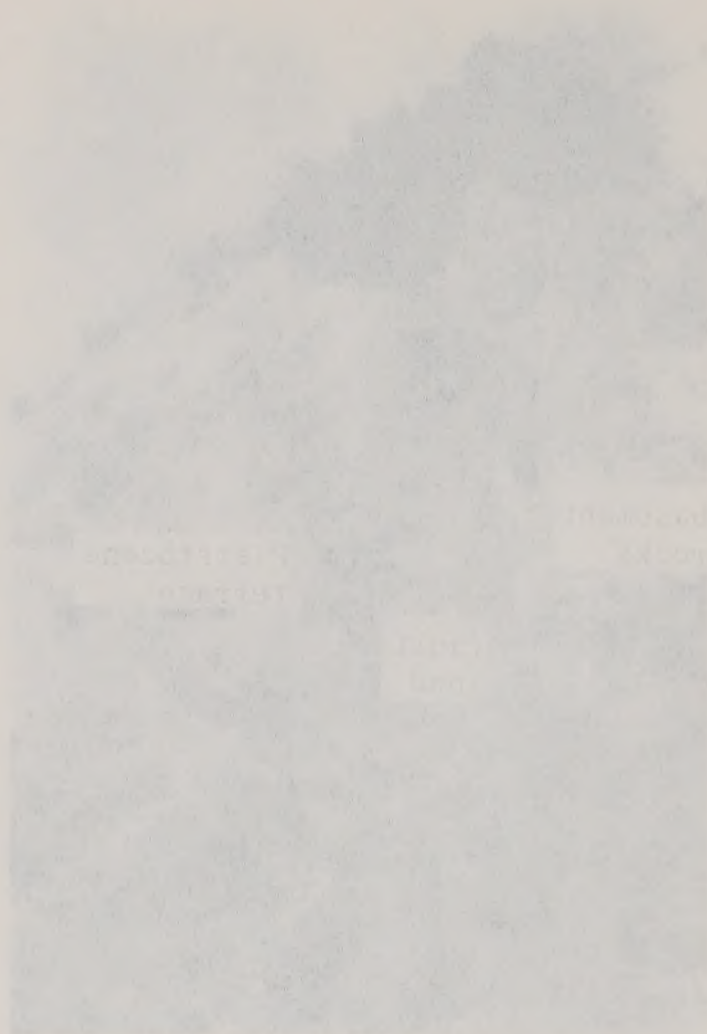


Figure 1A. Views of Varadun fault exposed at north
end of Church's Court.

b. Activity

The State Geologic Map (Jennings and Strand, 1969) shows the Verdugo fault as being buried beneath both Recent (Holocene) alluvium and Pleistocene nonmarine. However, the exposure at Church's Court and the references noted above indicating rupture in the older alluvial units indicate that the fault does cut Pleistocene rocks. Study of aerial photographs (Fairchild 6630-96 through 100 dated October 6, 1940, and LIA, L2, and L2A, no date) and reconnaissance of the area, however, indicate no evidence for rupture of Recent alluvium. On this basis, the fault can be considered as potentially active. That is, it cuts Pleistocene rocks, but does not appear to cut Holocene rocks. However, "direct evidence" as noted in the policies of the State Mining and Geology Board (1973) is lacking to prove the fault does not cut Holocene rocks. There is not now a Special Studies Zone (Alquist-Priolo Geologic Hazards Act) along this fault, but one may be established by the State Geologist at some time in the future. Also, the offset relationship between the Verdugo and Stough Canyon faults suggests the latter should also be considered as potentially active, and a Special Studies Zone may be established along it.

3. Sierra Madre-San Fernando Fault System

The Sierra Madre-San Fernando fault system is a complex system of reverse and thrust faults stretching from Cajon Pass in San Bernardino County to Ventura. This system includes the Cucamonga, Sierra Madre, San Fernando, and Santa Susana faults. The fault system trends generally east-west and involves older rocks to the north being pushed up against, and in many instances over, younger rocks to the south.

The part of this fault system closest to Burbank is the Sierra Madre fault that extends along the base of the San Gabriel Mountains between Sunland and La Crescenta. This fault is 4.5 miles northeast of the approximate limit of development at the base of the Mountains in Burbank, and approximately 9 miles from the southwestern corner of the City.

The principal hazard at Burbank from the Sierra Madre fault is ground shaking that would result from an earthquake on this segment of the fault system similar to that which occurred in San Fernando in 1971. The Richter magnitude of this earthquake was 6.6 which is similar to the maximum probable earthquake of magnitude 6.7 assigned to this fault by the Division of Mines and Geology (Greensfelder, 1973). Studies of recurrence intervals for earthquakes in

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this range of magnitude 6.4-6.7 by Lamar, Merifield and Proctor (1973) indicate a recurrence of about 200 years. This recurrence interval agrees well with findings from studies conducted on the San Fernando fault after the February 9, 1971 earthquake. These studies indicate that another earthquake of perhaps larger magnitude than the 6.6 February 9 shock, had occurred approximately 200 years earlier (Bonilla, 1973).

Dr. Clarence Allen of the California Institute of Technology suggests (in Lamar, et al, 1973) that the maximum credible earthquake, which could occur somewhere along Sierra Madre system, could have a magnitude of 7.5, and a recurrence interval of about 200 years. This recurrence interval is for the entire Sierra Madre system. The magnitude 7.5 event can be expected about every 600 years on the Sierra Madre segment of the fault system, if nine feet of movement (Lamar, Merifield and Proctor, 1973) is assumed for each event. The maximum credible earthquake is normally applied to structures such as atomic power plants, but is not normally a design consideration for normal uses or critical uses such as hospitals or schools.

4. San Andreas Fault

The San Andreas fault zone has been divided by Allen (1968) into several areas of contrasting behavior (Figure 15). The area of particular interest is the segment between San Bernardino and Parkfield that generated the Fort Tejon earthquake of 1857. This was one of the three "great earthquakes" of California's historic record, and this segment of the fault has not moved since. It is the closest part of the fault to Burbank and it is generally considered as the segment capable of generating the largest earthquake.

The segments of the fault to the northwest and southeast of the 1857 break are "active areas" that experience earthquakes of medium to small magnitude on a fairly regular basis. The 1857 break, however, is not moving, but is storing energy. The approximate rate of this storage can be deduced from the movements at either end. Pertinent data, summarized in Table 4 indicate that movement in the northwest is occurring at a rate of 5-6 cm/yr while that in the southwest is approximately 8.5 cm/yr. Current theory suggests that the differential between the two rates is being taken up in the Transverse Ranges near the south end of the segment, and that a rate of approximately 5-6 cm/yr is applicable to most of the segment of the 1857 break. This rate is compatible with other considerations (Brune et al, 1969) relating to movement on the fault.

this range of magnitude 6.4-6.7 by Lamont, Merrill and Proctor (1973) indicate a recurrence of about 100 years. This recurrence interval agrees well with findings from studies conducted on the San Bernardino fault after the February 9, 1971 earthquake. These studies indicate that another earthquake of perhaps larger magnitude than the 6.6 February 9 shock, and occurred approximately 100 years earlier (Bonilla, 1973).

Dr. Clarence Allen of the California Institute of Technology suggests (in Lamont, et al, 1973) that the maximum credible earthquake, which could occur somewhere along the San Bernardino fault, could have a magnitude of 7.5, and a recurrence interval of about 500 years. This recurrence interval is for the entire San Bernardino system. The magnitude 7.5 event can be expected about every 500 years on the San Bernardino segment of the fault system. It also has been argued (Lamont, Merrill and Proctor, 1973) that the recurrence interval for the maximum credible earthquake is normally applied to structures such as atomic power plants, but is not normally a design consideration for normal uses or critical uses such as hospitals or schools.

4. San Andreas Fault

The San Andreas fault zone has been divided by Allen (1968) into several areas of contrasting behavior (Figure 15). The area of greatest interest is the segment between San Bernardino and Parkfield that generated the Fort Tejon earthquake of 1857. This was one of the three "great earthquakes" of California's historic record, and this segment of the fault has not moved since. It is the closest part of the fault to Burbank and it is generally considered as the segment capable of generating the largest earthquake.

The segments of the fault to the northwest and southeast of the 1857 break are "active areas" that experience earthquakes of medium to small magnitude on a fairly regular basis. The 1857 break, however, is not moving, but is storing energy. The approximate rate of this storage can be deduced from the movements at either end. Pertinent data, summarized in Table 4 indicate that movement in the northwest is occurring at a rate of 5-6 cm/yr while that in the southeast is approximately 8.5 cm/yr. Current theory suggests that the differential between the two rates is being taken up in the Transverse Ranges near the south end of the segment, and that a rate of approximately 5-6 cm/yr is applicable to most of the segment of the 1857 break. This rate is compatible with other considerations (Brune et al, 1969) relating to movement on the fault.

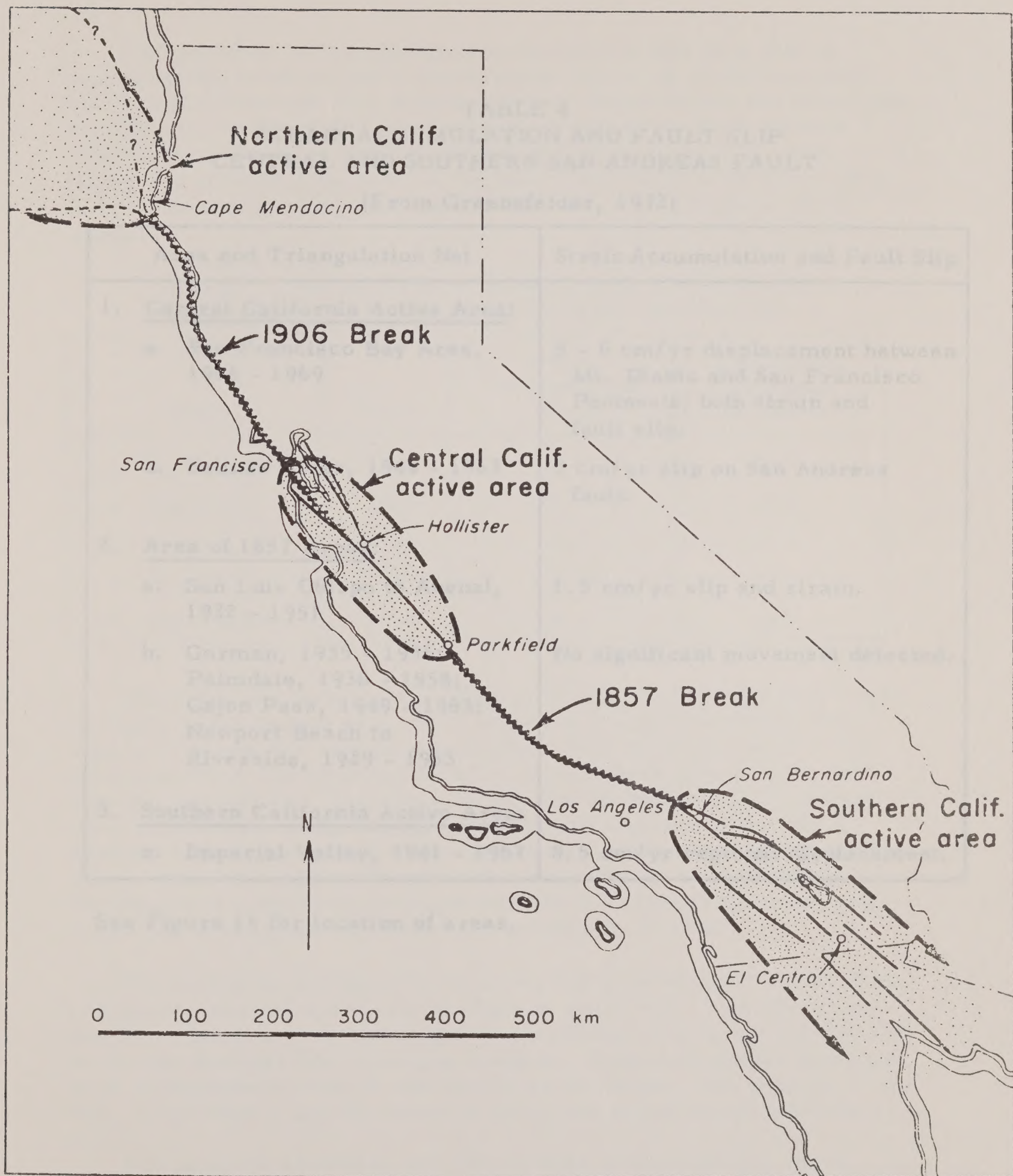


Figure 15. Areas of contrasting seismic behavior along the San Andreas fault zone in California. From Allen, 1968.



Figure 15. Areas of contrasting seismic behavior along the San Andreas fault zone in California. From Allen, 1965.

TABLE 4
STRAIN ACCUMULATION AND FAULT SLIP
CENTRAL AND SOUTHERN SAN ANDREAS FAULT

(From Greensfelder, 1972)

Area and Triangulation Net	Strain Accumulation and Fault Slip
1. <u>Central California Active Area:</u>	
a. San Francisco Bay Area, 1906 - 1969	5 - 6 cm/yr displacement between Mt. Diablo and San Francisco Peninsula; both strain and fault slip.
b. Salinas River, 1944 - 1963	3 cm/yr slip on San Andreas fault.
2. <u>Area of 1857 Break:</u>	
a. San Luis Obispo to Avenal, 1932 - 1951	1.5 cm/yr slip and strain.
b. Gorman, 1935 - 1956; Palmdale, 1938 - 1958; Cajon Pass, 1949 - 1963; Newport Beach to Riverside, 1929 - 1953	No significant movement detected.
3. <u>Southern California Active Area:</u>	
a. Imperial Valley, 1941 - 1967	8.5 cm/yr regional displacement.

See Figure 15 for location of areas.

TABLE 4
STRAIN ACCUMULATION AND FAULT SLIP
CENTRAL AND SOUTHERN SAN ANDREAS FAULT

(From Greenfelder, 1973)

Area and Triangulation Net	Strain Accumulation and Fault Slip
1. <u>Central California Active Areas:</u>	
a. San Francisco Bay Area, 1908 - 1969	2 - 6 cm/yr displacement between Mt. Diablo and San Francisco Peninsula; both strain and fault slip.
b. Salinas River, 1944 - 1963	3 cm/yr slip on San Andreas fault.
2. <u>Area of 1857 Earthquake:</u>	
a. San Luis Obispo to Avama, 1932 - 1951	1.5 cm/yr slip and strain.
b. Gorman, 1935 - 1950; Palmdale, 1938 - 1958; Cajon Pass, 1949 - 1963; Newport Beach to Riverside, 1959 - 1963	No significant movement detected.
3. <u>Southern California Active Areas:</u>	
a. Imperial Valley, 1941 - 1967	8.5 cm/yr regional displacement.

See Figure 15 for location of areas.

The magnitude of the earthquake generated by slip on a fault is approximately proportional to the logarithm (base 10) of the movement (surface displacement) that occurs. Data on displacement and magnitude compiled by Bonilla (1970) for the San Andreas and faults of similar movement are listed in Table 5 and are plotted on Figure 16. The fitting of a straight-line curve to the data is somewhat arbitrary, and in this process the values for the San Andreas itself are given more weight.

TABLE 5. FAULT DISPLACEMENT AND EARTHQUAKE MAGNITUDE LATERAL FAULTS IN CALIFORNIA

Fault	Year	Fault Displacement (feet)	Earthquake Magnitude (Richter)
1. San Andreas	1906	20	8.3
2. Imperial	1940	19	7.1
3. Mannix	1947	0.25	6.4
4. Impertial	1966	0.05	3.6
5. San Andreas	1966	0.6	5.5

Magnitude and displacement (Figure 16) can be combined with a rate of displacement to give recurrence intervals for various magnitudes. Figure 17 shows this relationship for four rates of displacement. The most important consideration is that 117 years have passed since this segment last moved. Regardless of the rate of displacement assumed, there is probably enough energy stored in this segment of the San Andreas fault to generate a major earthquake at any time. If a 6 cm/yr rate is valid, the energy stored already is sufficient to generate an earthquake of a magnitude of approximately 8.3. This is the estimated magnitude of the great San Francisco earthquake of 1906.

The reasoning developed in the paragraphs above is not new to most geologists, seismologists, and earthquake engineers. It is the reason one hears from time-to-time about the prediction of a "great earthquake" on the San Andreas fault near Los Angeles. From a scientific standpoint, such an earthquake must be considered as imminent. The question is not "if", it is "when", and the longer it waits, the larger it will probably be.

For purposes of further analysis in later sections of this report, the magnitude of the expected earthquake is taken at 8.5. No specific

The magnitude of the earthquake generated by slip on a fault is approximately proportional to the logarithm (base 10) of the movement (surface displacement) that occurs. Data on displacement and magnitude compiled by Benalla (1930) for the San Andreas and faults of similar movement are listed in Table 2 and are plotted on Figure 16. The fitting of a straight-line curve to the data is somewhat arbitrary, and in this process the values for the San Andreas itself are given more weight.

TABLE 2. FAULT DISPLACEMENT AND EARTHQUAKE MAGNITUDE LATERAL FAULTS IN CALIFORNIA

Fault	Year	Fault Displacement (feet)	Earthquake Magnitude (Richter)
1. San Andreas	1906	20	8.3
2. Imperial	1940	18	7.1
3. Mauniz	1947	0.35	6.4
4. Imperial	1966	0.68	3.6
5. San Andreas	1966	0.6	2.2

Magnitude and displacement (Figure 16) can be combined with a rate of displacement to give recurrence intervals for various magnitudes. Figure 17 shows this relationship for four rates of displacement. The most important consideration is that 117 years have passed since this segment last moved. Regardless of the rate of displacement assumed, there is probably enough energy stored in this segment of the San Andreas fault to generate a major earthquake at any time. If a 6 cm/yr rate is valid, the energy stored already is sufficient to generate an earthquake of a magnitude of approximately 8.3. This is the estimated magnitude of the great San Francisco earthquake of 1906.

The reasoning developed in the paragraphs above is not new to most geologists, seismologists, and earthquake engineers. It is the reason one hears from time to time about the prediction of a "great earthquake" on the San Andreas fault near Los Angeles. From a scientific standpoint, such an earthquake must be considered as imminent. The question is not "if", it is "when", and the longer it waits, the larger it will probably be.

For purposes of further analysis in later sections of this report, the magnitude of the expected earthquake is taken as 8.3. No specific

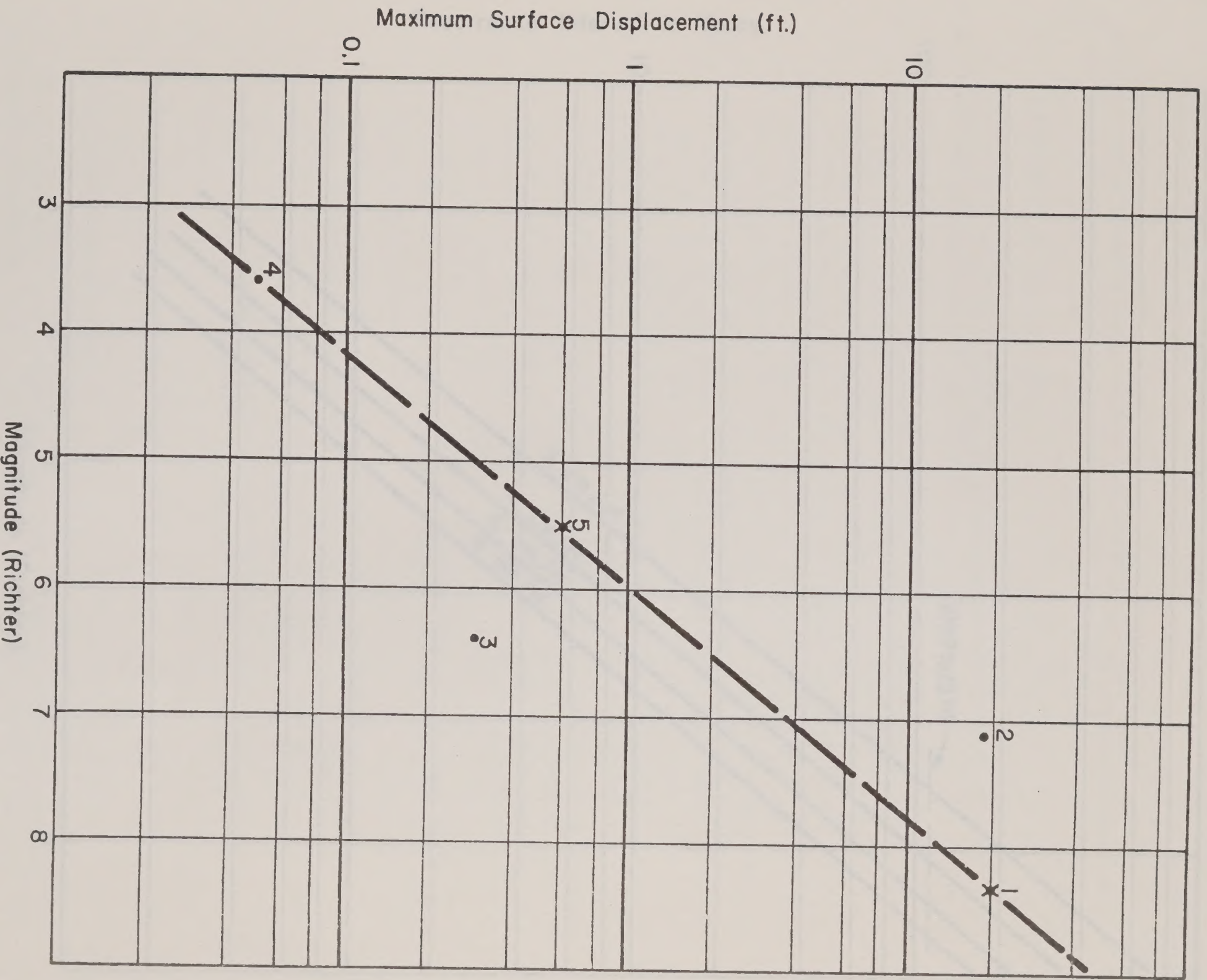
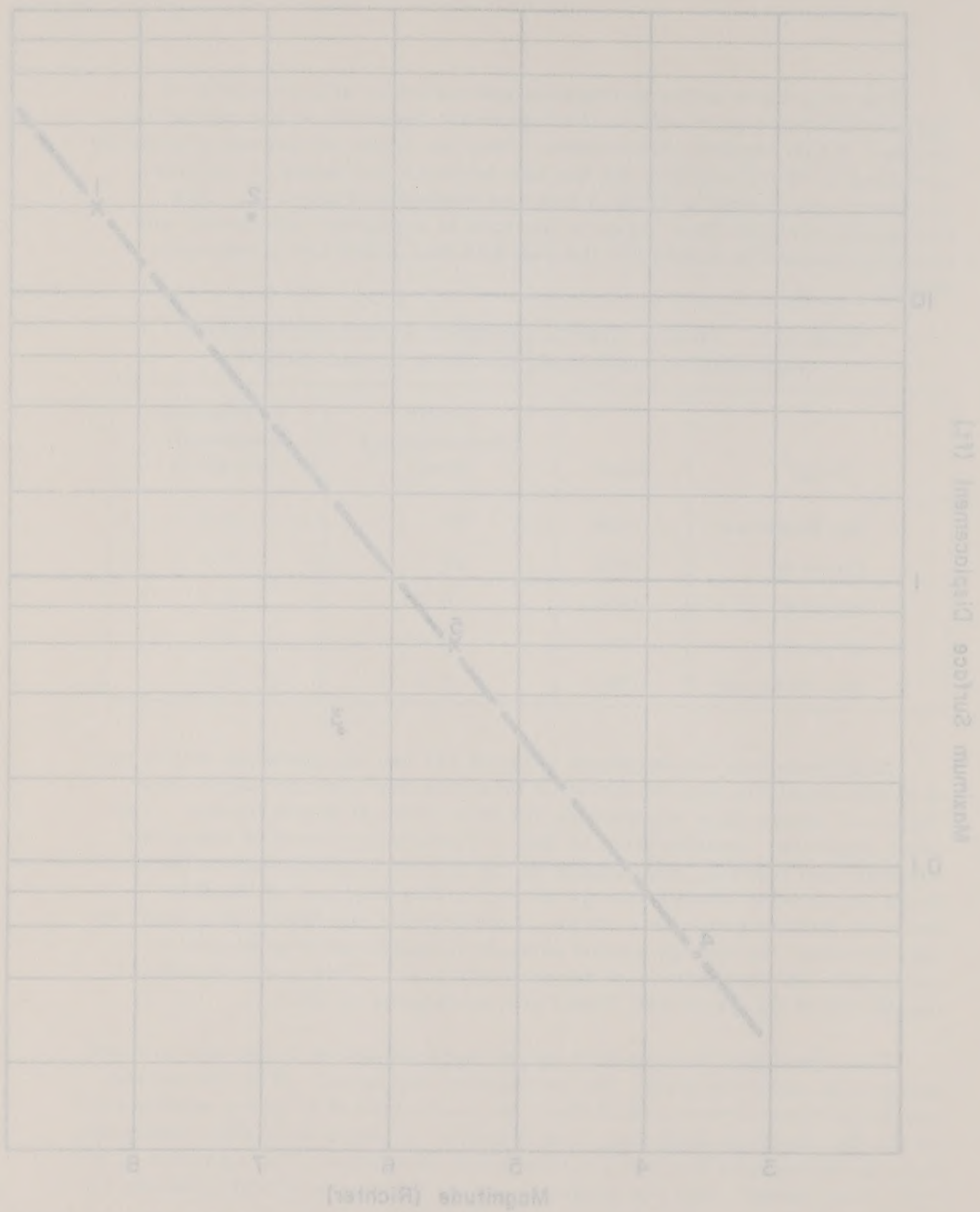


Figure 16. Earthquake magnitude vs. surface displacement for strike-slip faults. Data from Bonilla, 1970.

Figure 16. Earthquake magnitude vs. surface displacement for strike-slip faults. Data from Bonini, 1976.

* Other lateral faults
X San Andreas fault



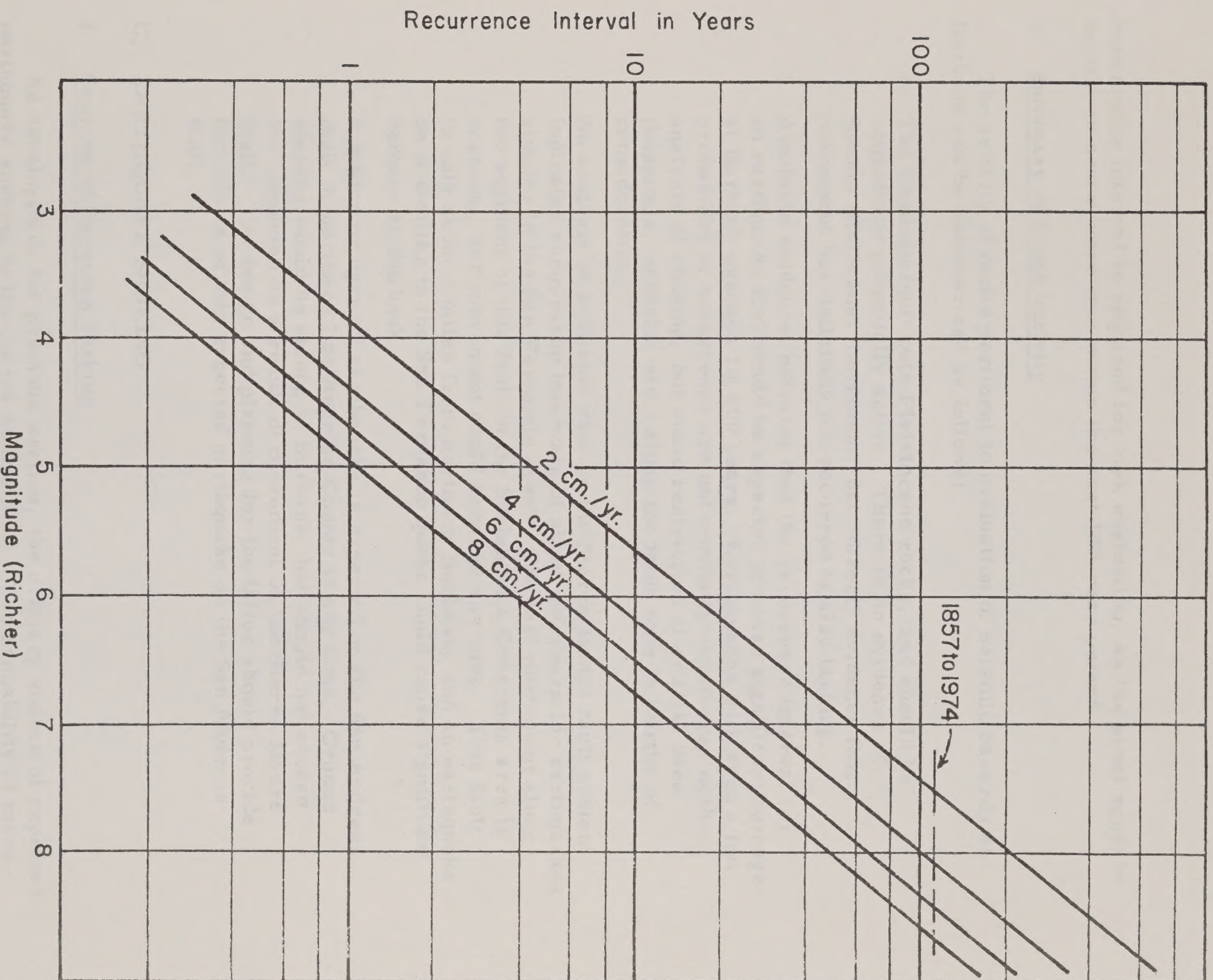


Figure 17. Recurrence vs. earthquake magnitude, San Andreas fault.

area, such as the Newport-Inglewood fault to the south, would also be taken into account by planning and designing for the expected earthquake from the Sierra Madre fault.

2. Intensity of Recorded Earthquakes

The intensity of shaking as observed during past earthquakes can, for some locations, provide data on shaking that can be expected in the future. In this regard the most significant event was the 1971 San Fernando earthquake. It was approximately the same magnitude and was located on the same fault system as the expected event on the Sierra Madre fault. The latter, however, will occur on the next segment of the fault to the east, and will therefore be closer to Burbank and will generate stronger shaking there.

The distribution of Mercalli intensity in the area affected by this earthquake is shown on Figure 18. The maximum intensity of VIII to XI was observed in San Fernando near the line of fault rupture, and the intensities above VIII are generally attributed to fault rupture rather than shaking. (See Introduction for discussion of Mercalli Intensity Scale.) The intensity in Burbank was VII, and this level extended southeastward as far as Los Angeles and Pasadena.

The pattern of shaking intensity from a similar event on the Sierra Madre should be similar to that of Figure 18 except that the southeasterly shifting of the source area would shift the intensity VIII zone into the Burbank area.

3. Engineering Characteristics of Expected Earthquakes

a. Methodology

The derivation of the engineering characteristics of a particular earthquake at a particular site is normally a two-step process. These steps are the two considerations that have been discussed in describing the changes in earthquake intensity; that is, distance to the source of the earthquake and local conditions. Where the distance factor is treated as the travel path in deep bedrock, the effect of local conditions is the near-surface amplification of the waves as they travel upward through layered rocks. The mathematics and geometry of this calculation are shown in Figure 19. The distance problem is a relatively simple part of the calculation. However, near-surface amplification and the choice of type earthquakes are more complex problems to be discussed in detail in the next two sections.

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2. Intensity of Recorded Earthquakes

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The distribution of Mercalli intensity in the area affected by this earthquake is shown on Figure 18. The maximum intensity of VII to XI was observed in San Fernando near the line of fault rupture, and the intensities above VII are generally attributed to fault rupture rather than shaking. (See introduction for discussion of Mercalli intensity Scale.) The intensity in Borwick was VII, and this level extended southward as far as Los Angeles and Pasadena.

The pattern of shaking intensity from a similar event on the Sierra Madre should be similar to that of Figure 18 except that the contours reflecting the same intensity would shift with the intensity VII zone into the Borwick area.

3. Engineering Characteristics of Expected Earthquake

a. Methodology

The derivation of the engineering characteristics of a particular earthquake as a particular one is normally a two-step process. These steps are the two considerations that have been discussed in describing the changes in earthquake intensity that are due to distance from the source of the earthquake and local conditions. Where the distance factor is treated as the travel path in deep bedrock, the effect of local conditions is the near-surface amplification of the waves as they travel upward through layered rocks. The mathematics and geometry of this calculation are given in Figure 19. The distance problem is a relatively simple part of the calculation. However, near-surface amplification and the choice of type wavefunctions are more complex problems to be discussed in detail in the next two sections.

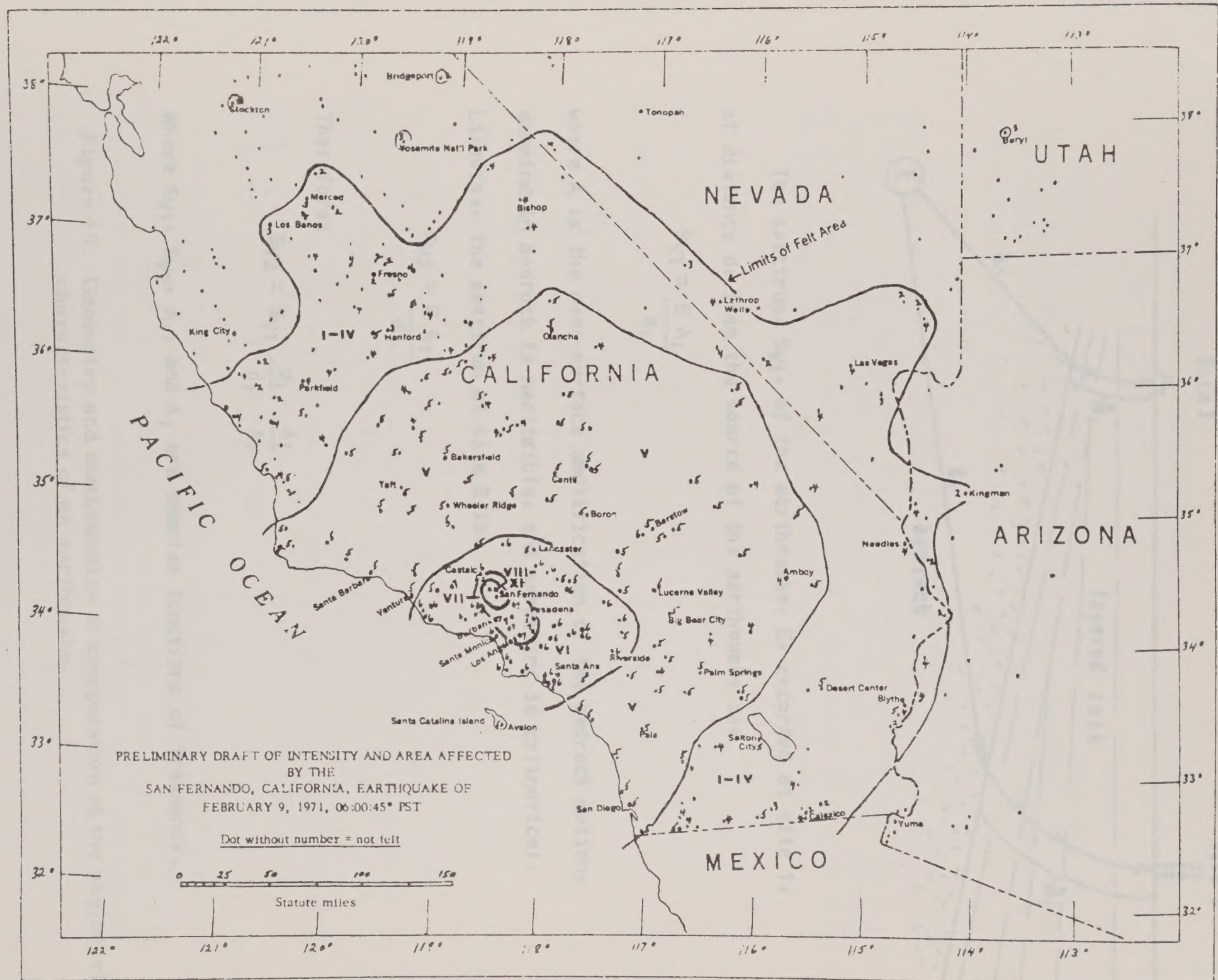
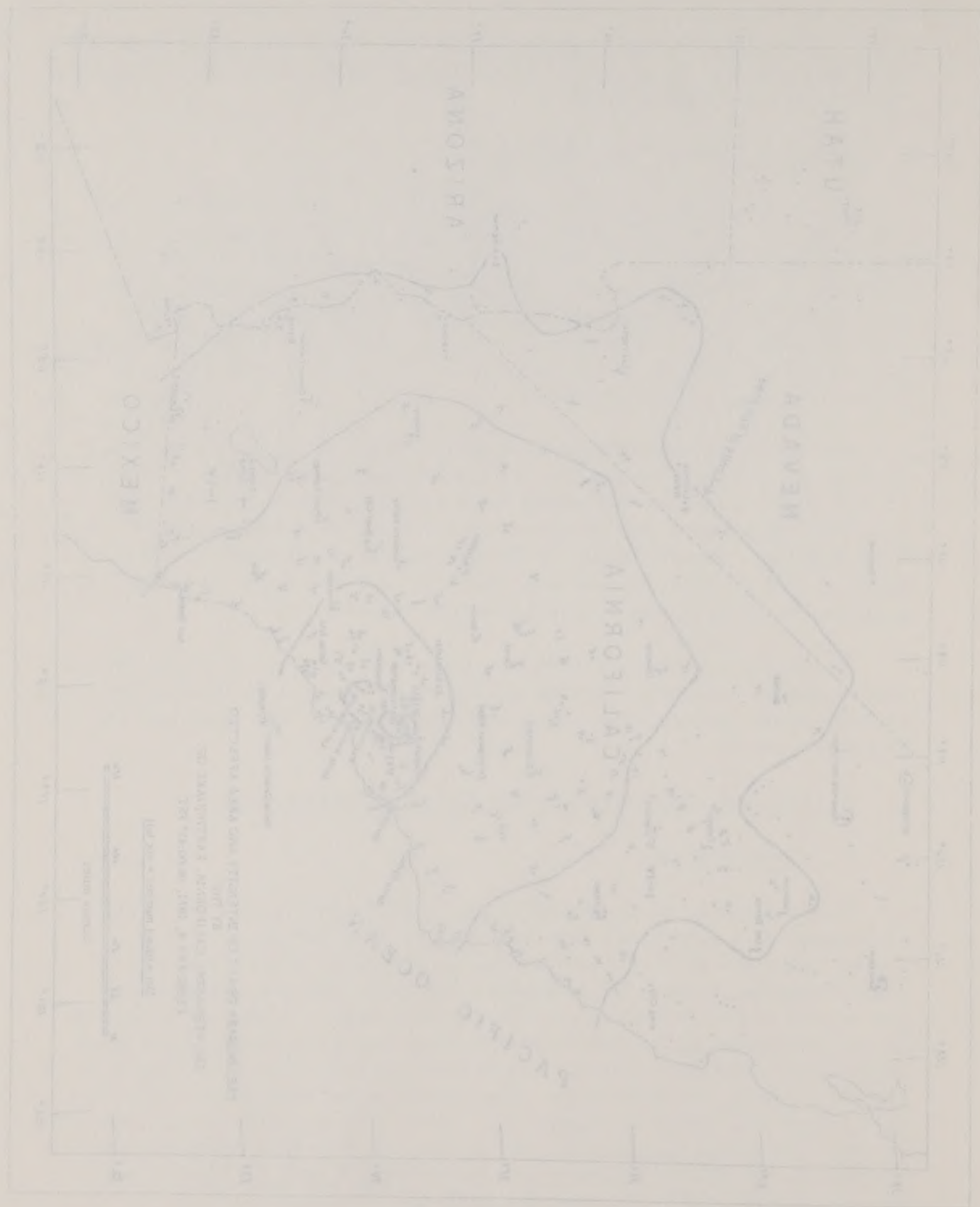
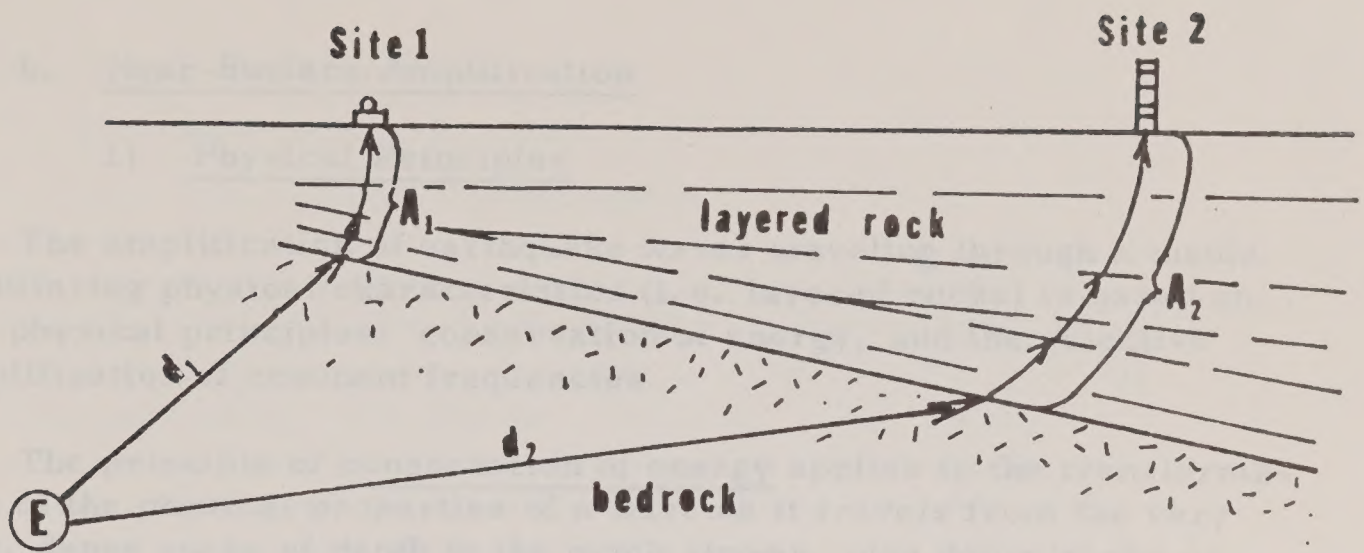


Figure 8. Intensity and area affected by the 1971 San Fernando earthquake.
From Scott, 1971.





The spectrum, S_{V1} , of the earthquake, E, recorded at site 1, at distance d_1 from the source of the earthquake is:

$$S_{V1} = \frac{E A_1}{d_1}$$

where A is the near-surface amplification of the bedrock motion, damping in bedrock is negligible, and spreading is cylindrical.

Likewise, the spectrum at site 2 is:

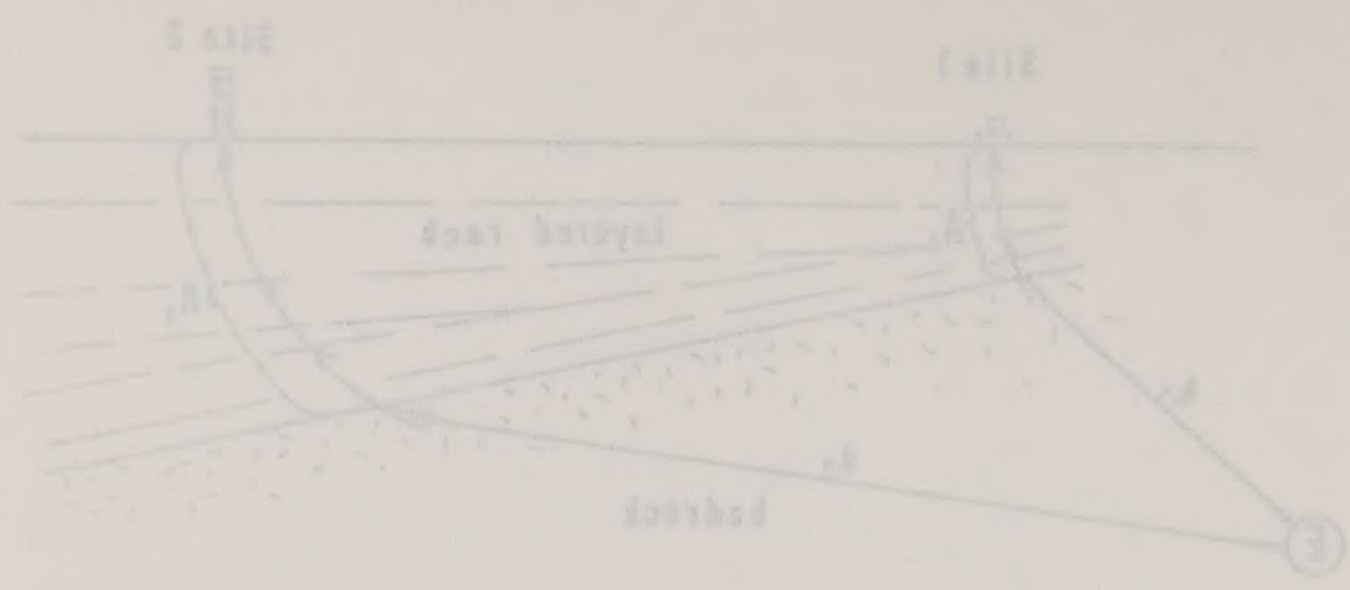
$$S_{V2} = \frac{E A_2}{d_2}$$

Therefore:

$$S_{V2} = S_{V1} \frac{d_1}{d_2} \frac{A_1}{A_2}$$

Where S_{V1} , S_{V2} , A_1 , and A_2 are complex functions of frequency.

Figure 19. Geometry and mathematics of computation of the engineering characteristics of an earthquake.



The spectrum, S_{Y_1} , of the earthquake, E , recorded at site 1, at distance d_1 from the source of the earthquake is:

$$S_{Y_1} = \frac{E A_1}{d_1}$$

where A_1 is the near-surface amplification of the bedrock motion, assuming the bedrock is horizontal, and recording is cylindrical.

Likewise, the spectrum at site 2 is:

$$S_{Y_2} = \frac{E A_2}{d_2}$$

Therefore:

$$S_{Y_2} = S_{Y_1} \frac{d_1}{d_2} \frac{A_2}{A_1}$$

where S_{Y_1} , S_{Y_2} , A_1 , and A_2 are complex functions of frequency.

Figure 10. Geometry and mathematics at computation of the magnitude characteristic of an earthquake.

b. Near-Surface Amplification

1) Physical Principles

The amplification of earthquake waves traveling through a media of differing physical characteristics (i.e. layered rocks) is based on two physical principles: conservation of energy, and the selective amplification of resonant frequencies.

The principle of conservation of energy applies to the transformation of the physical properties of a wave as it travels from the very fast, dense rocks at depth to the much slower, less dense rocks or soils at the surface. In this conversion, the energy of wave velocity is converted to energy of wave amplitude. The mathematical expression for this change as a wave travels from layer 1 to layer 2 is:

$$AR = \frac{D_2 V_2}{D_1 V_1}$$

where: AR = amplification ratio (layer 2 to layer 1),

D_1 = density of layer 1,

D_2 = density of layer 2,

V_1 = velocity of layer 1, and

V_2 = velocity of layer 2.

The above equation involves both velocity and density, but velocity is by far the most important. In the overall change from granite at depth to an average soil at the surface, the density will typically change from 2.7 to about 1.5; a ratio of less than 2:1. Velocity (shear-wave) on the other hand will typically change from about 11,000 ft/sec to less than 500 ft/sec; a ratio of more than 20:1, and 10 times the density change.

The selective amplification of resonant frequencies is more complex, but in simple terms, the rock layers act somewhat like a series of organ pipes that amplify waves of particular frequencies. The frequencies that are amplified are those that form a one-quarter-wavelength standing wave in the layer, and all higher modes. The dominant periods of a layer are thus:

$$T = \frac{4}{1} \frac{H}{V}, \frac{4}{3} \frac{H}{V}, \frac{4}{5} \frac{H}{V}, \text{ etc.}$$

1) Physical Principles

The amplification of surface waves traveling through a medium of varying physical characteristics (i.e., layered rock) is based on two physical principles: conservation of energy, and the selective amplification of resonant frequencies.

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where: AR = amplification ratio (layer 2 to layer 1),

D_1 = density of layer 1,

D_2 = density of layer 2,

V_1 = velocity of layer 1, and

V_2 = velocity of layer 2.

The above equation involves both velocity and density, but velocity is by far the most important. In the overall change from greater at depth to an average at the surface, the density will typically change from 2.5 to about 1.8 a ratio of less than 5:1. Velocity (shear-wave) on the other hand will typically change from about 1,500 ft/sec to less than 500 ft/sec; a ratio of more than 3:1, and 10 times the density change.

The selective amplification of resonant frequencies is more complex, but in simple terms, the rock layers act somewhat like a series of organ pipes that amplify waves at particular frequencies. The frequencies that are amplified are those that form a one-quarter wavelength standing wave in the layer, and all higher modes. The dominant periods of a layer are then:

$$T = \frac{4H}{V}, \frac{4H}{3V}, \frac{4H}{5V}, \text{ etc.}$$

where: T = dominant period,
 H = layer thickness, and
 V = layer velocity (shear wave).

For most sites, with many layers of varying thickness and a gradual increase of velocity with depth, selective amplification is secondary in importance to the more general amplification due to decreasing velocity and density. However, where there is a very pronounced velocity change at relatively shallow depth, as in the Mexico City area discussed in the Introduction, the concentration of energy in a narrow frequency range can be very important for structures having a similar natural period of vibration.

In addition to the two principles considered above, damping can be important for sites with thick layered sequences. Waves traveling in fast, dense rocks such as granite are almost unaffected by damping, but unconsolidated materials such as soils, soft sands and shales can effectively damp earthquake waves if they are present in sufficient thickness. Overall, the effect is to cancel a part of the wave amplification of the slow, less dense rocks, because rocks with high amplification characteristics generally have high damping factors. For damping to be effective, however, thick layers are required. Thus, low velocity materials may be "good" or "bad". If, they are present as a relatively thin layer (15-100 feet), amplification may be very significant. However, if they are present as very thick layers (several thousands of feet), damping can be effective in reducing the amplification normally expected at sites underlain by low velocity rocks.

From the discussion above it is apparent that the most important physical characteristic of a site is the velocity or velocities of the layers underlying the site. Density is less important, and it can be estimated from velocity if the rock types are known. Damping is important for thick sections, and it too is closely related to velocity. Thus, if the velocity of the wave type of interest is known, the density and damping can generally be estimated to an acceptable degree of accuracy.

Earthquake shaking is the result of complex combinations of several types of vibrational waves. The primary components of earthquake waves are the so-called body waves that travel through the deeper parts of the earth's crust. Body waves include

where: T = dominant period,
 h = layer thickness, and
 V = layer velocity (shear wave).

For most sites, with many layers of varying thickness and a gradual increase of velocity with depth, such a simple amplification is secondary in importance to the more general amplification due to decreasing velocity and density. However, where there is a very pronounced velocity change at relatively shallow depth, as in the Mexico City area discussed in the introduction, the consideration of energy in a narrow frequency range can be very important for structures having a similar natural period of vibration.

In addition to the two principles considered above, damping can be important for sites with thick layered sequences. Waves traveling in soft, loose rocks such as granite are almost not affected by damping, but unconsolidated materials such as sands, soft sands and shales can effectively damp earthquake waves if they are present in sufficient thickness. Overall, the effect is to cancel a part of the wave amplification at the slow, less dense rocks, because rocks with high amplification characteristics generally have high damping factors. For damping to be effective, however, thick layers are required. Thus, low velocity materials may be "good" or "bad". If they are present as a relatively thin layer (5-100 feet), amplification may be very significant. However, if they are present as very thick layers (several thousands of feet), damping can be effective in reducing the amplification normally expected at sites underlain by low velocity rocks.

From the discussion above it is apparent that the most important physical characteristic of a site is the velocity or velocities of the layers underlying the site. Density is less important, and it can be estimated from velocity if the rock types are known. Damping is important for thick sections, and it too is closely related to velocity. Thus, if the velocity of the wave type of interest is known, the density and damping can generally be estimated to an acceptable degree of accuracy.

Earthquake shaking is the result of complex combinations of several types of vibrational waves. The primary components of earthquake waves are the so-called body waves that travel through the deeper parts of the earth's crust. Body waves include

the primary (P-wave) or compressional waves and the secondary (S-wave) or shear waves. For waves traveling at depth, and refracted upward to the site, the P-waves, vibrating parallel to the propagation direction, dominate the vertical component of shaking. The S-waves arrive later and vibrate normal to the direction of propagation; they make up the major part of the damage-inducing, horizontal components of shaking. Thus, it is the shear waves that are of primary importance in the analysis of earthquake shaking.

2) Model Analysis

The analysis of near-surface amplification at Burbank is based on three computer-generated models, two of which are shown in Figures 20 and 21. Velocity data is not available for specific locations in Burbank, but the rocks and soils are similar to those in other parts of Southern California for which good data is available (Duke and Leeds, 1962 and Duke et al, 1971). Shear-wave, density, and damping for materials at Burbank were estimated from these sources, and layered models were developed for various thicknesses of alluvium over hard bedrock. The amplification spectra were computed and plotted by Mr. J. A. Johnson using the latest computer programs developed at the Earthquake Engineering Research Institute at UCLA. The application of these spectra will be discussed further under Microzonation.

c. Type Earthquake

The "type earthquake" used in the analysis of expected earthquake shaking at Burbank is the strong motion, accelerogram recorded in Glendale (633 E. Broadway) during the 1971 San Fernando earthquake. Conditions at the Glendale site are similar to those in much of the more populated parts of Burbank, and correction for this factor is minimal. The distance to the source fault is approximately 13 miles. A record closer to the source would provide a better match to this parameter, but they are not available from sites similar to those in Burbank.

The three traces (2 horizontal and 1 vertical component) of the accelerogram are shown in Figure 22, and the response spectrum is shown in Figure 23. The heavy dashed lines on the spectrum are the smoothed envelopes of both horizontal components for 0, 5 and 10% critical damping used in the derivation of response spectra for Burbank.

The primary (P-wave) or compressional waves and the secondary (S-wave) or shear waves, for waves traveling at depth, and reflected upward to the site, the P-waves, vibrating parallel to the propagation direction, dominate the vertical component of shaking. The S-waves arrive later and vibrate normal to the direction of propagation; they make up the major part of the damage-inducing, horizontal components of shaking. Thus, it is the shear waves that are of primary importance in the analysis of earthquake shaking.

2) Ground Analysis

The analysis of near-surface amplification at Burbank is based on three computer-generated models, two of which are shown in Figures 20 and 21. Velocity data is not available for specific locations in Burbank, but the rocks and soils are similar to those in other parts of Southern California for which good data is available (Gale and Heald, 1975 and Hukle et al., 1971). Shear-wave velocity, and damping for materials at Burbank were estimated from these sources, and layered models were developed for various thicknesses of alluvium over hard bedrock. The amplification spectra were computed and plotted by Mr. J. A. Johnson using the latest computer programs developed at the Earthquake Engineering Research Institute at U.C.L.A. The application of these spectra will be discussed further under Mitigation.

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The three traces (horizontal and 1 vertical component) of the acceleration are shown in Figure 22, and the response spectrum is shown in Figure 23. The heavy dashed lines on the spectrum are the smoothed envelopes of both horizontal components for 0.5 and 10% critical damping used in the derivation of response spectra for Burbank.

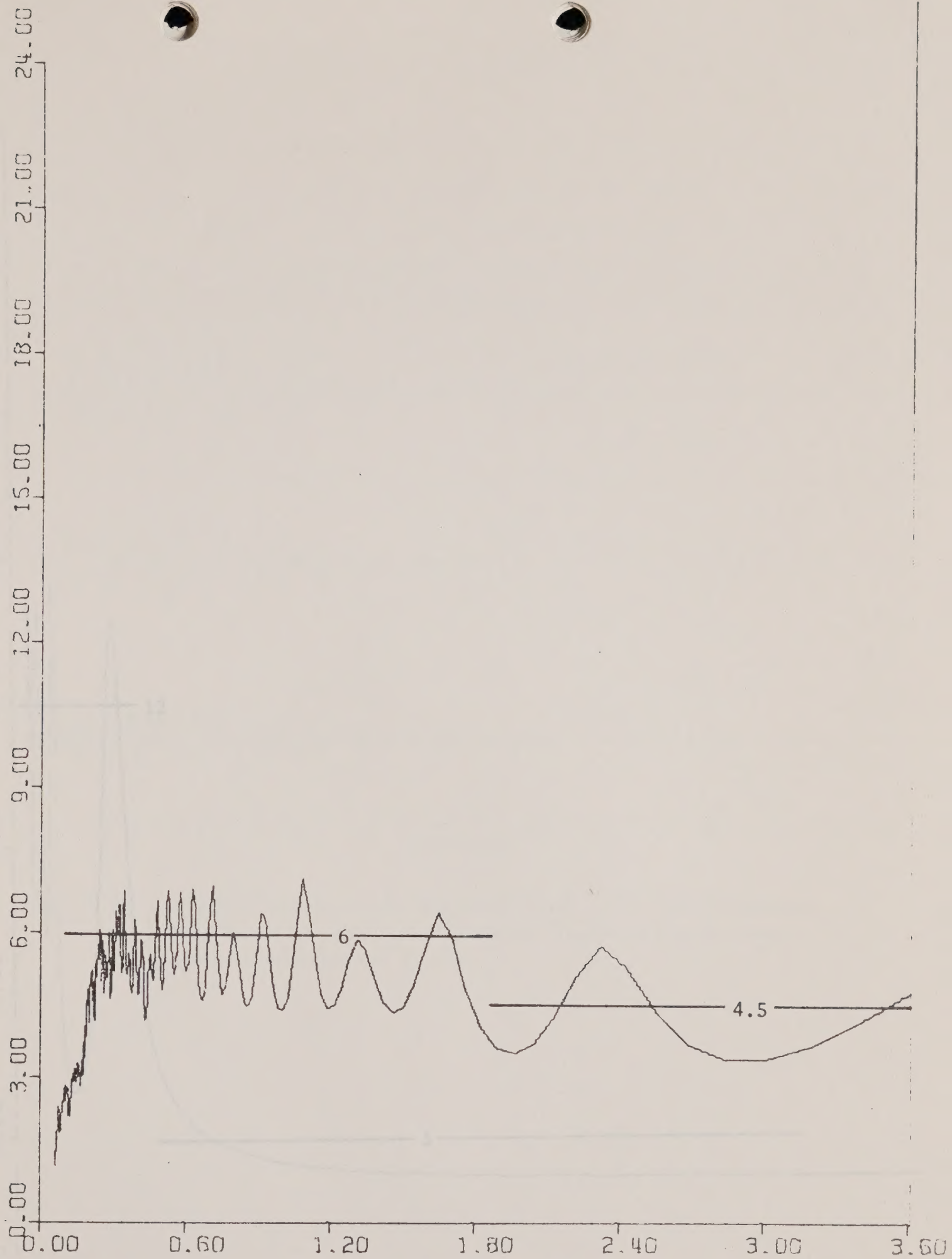


Figure 20. Amplification spectrum, thick alluvium over sedimentary and basement rocks.

Figure 21. Amplification spectrum, thin alluvium over basement rocks.

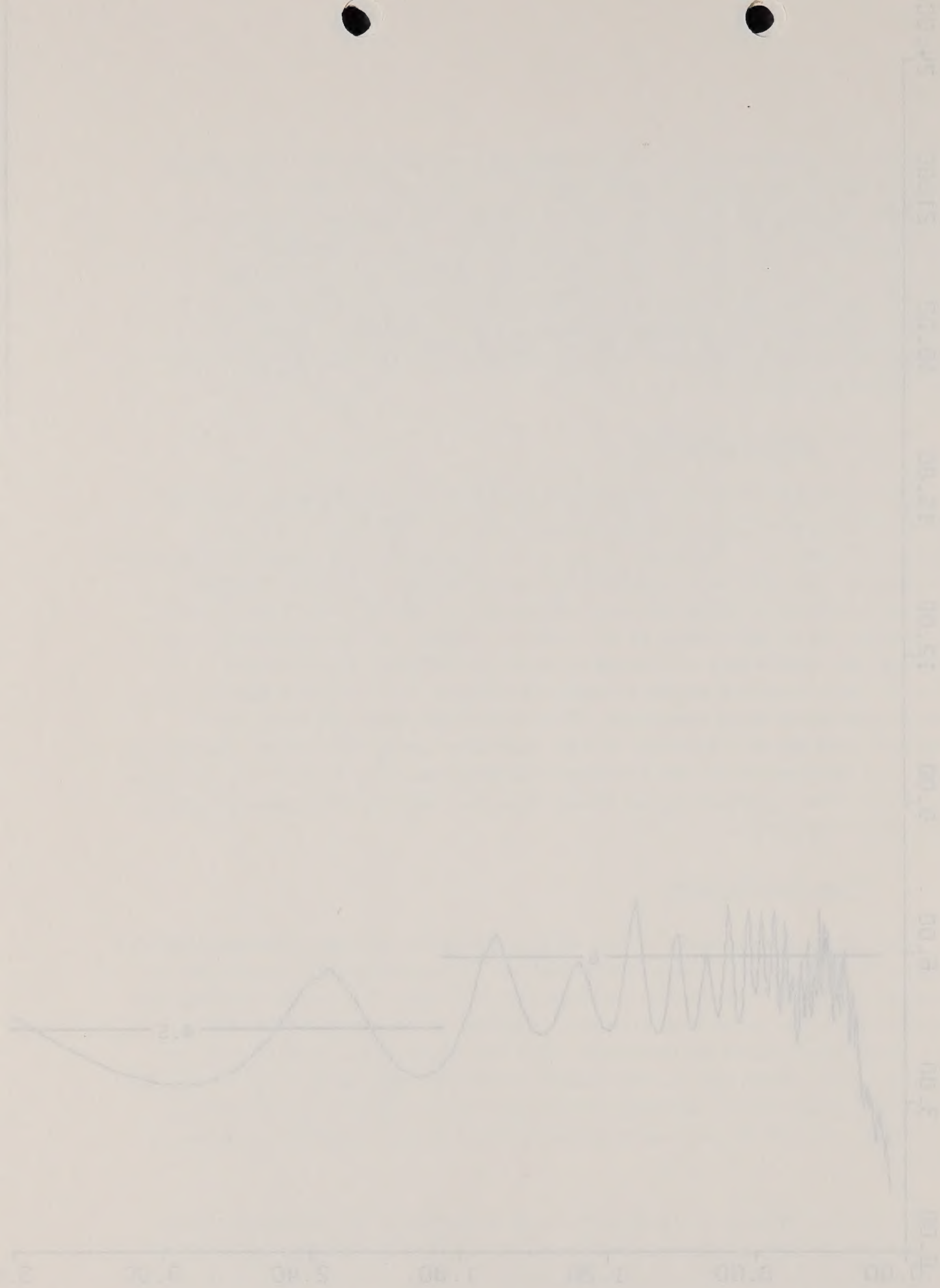


Figure 50. Amplification spectrum, thick silurian over sedimentary and basement rocks.

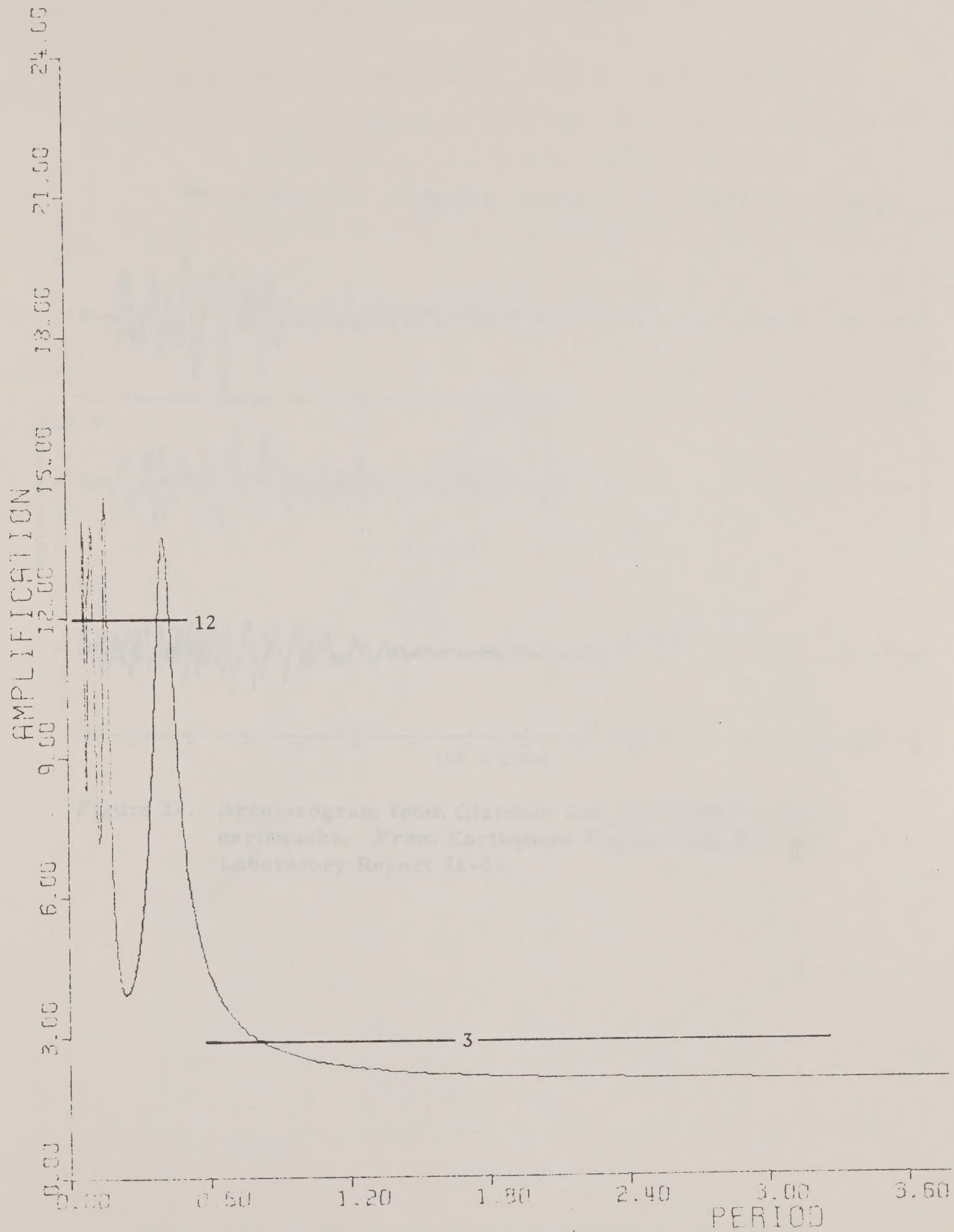


Figure 21. Amplification spectrum, thin alluvium over basement rocks



Figure 51. Amplification spectrum, thin silicon over
basement rocks

RESPONSE SPECTRUM

SAN FERNANDO EARTHQUAKE FEB 6, 1971 - 0600 PST

STATION 71.102.0 2/9/71 0600PST GLENDALE 038 E. 1 BROADWAY M.S. BLDG

SHAKE TABLE NO. 11, 2, 5, 10 AND 20 PERCENT OF DAMPING

IF088 71.102.0 2/9/71 0600PST GLENDALE 038 E. 1 BROADWAY M.S. BLDG

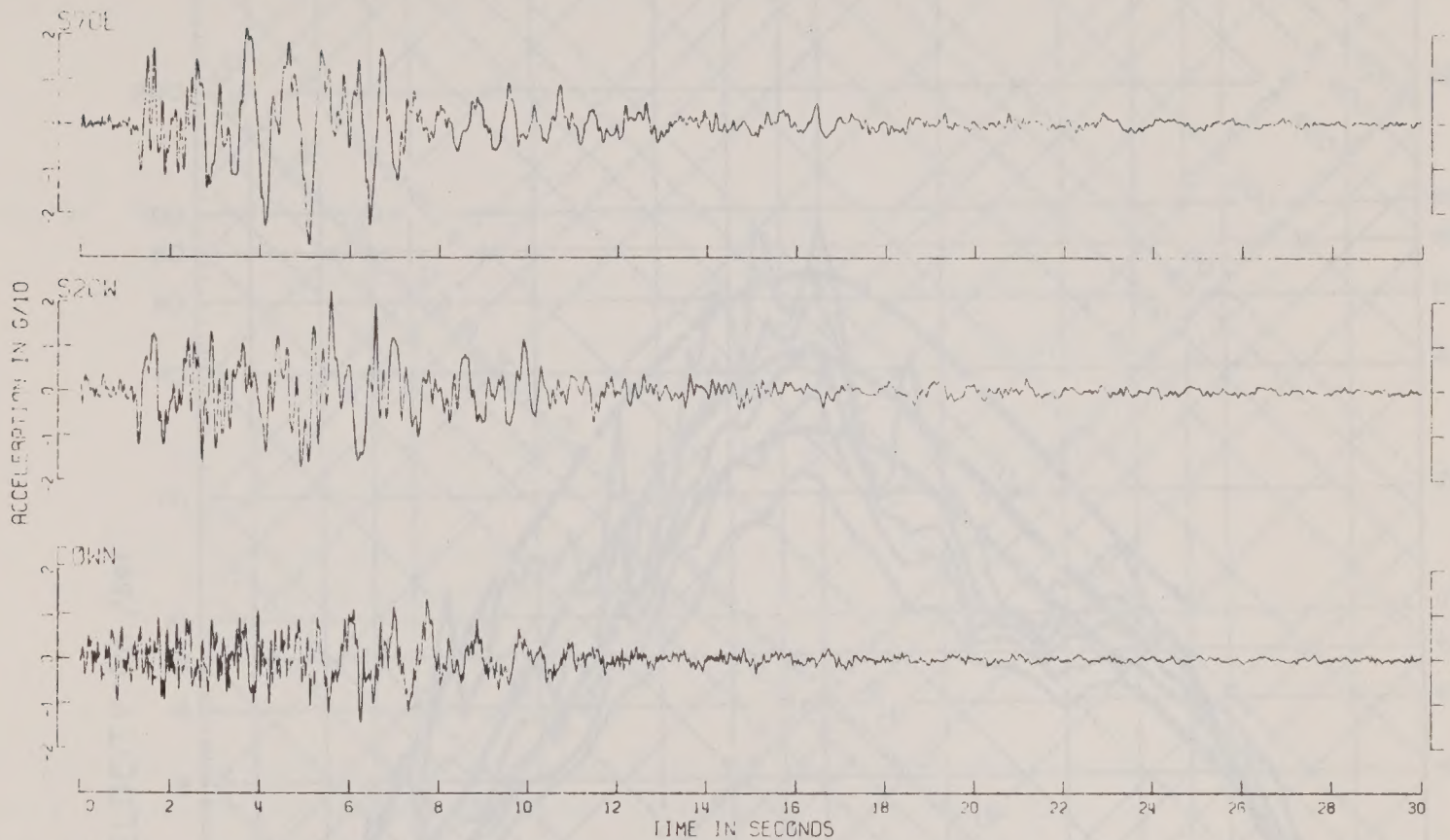


Figure 22. Accelerogram from Glendale site, 1971 San Fernando earthquake. From Earthquake Engineering Research Laboratory Report 71-23.

Figure 23. Response spectrum from Glendale site, 1971 San Fernando earthquake. The heavy dashed lines are smoothed envelopes of the two horizontal components for 5% and 10% critical damping. From Earthquake Engineering Research Laboratory Report 71-24.

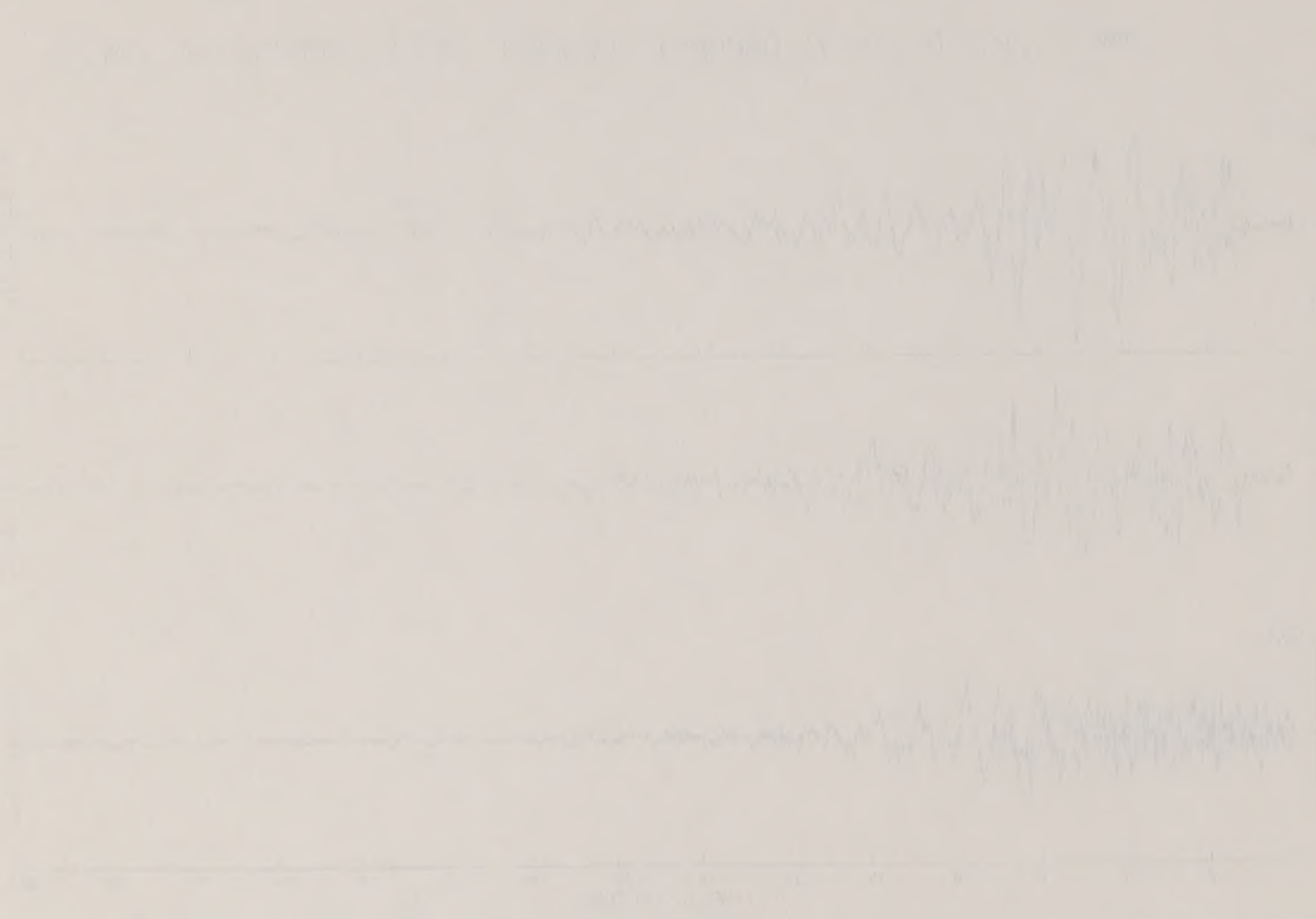


Figure 13. Accelerograms from Clatskanie site, 1971 San Fernando earthquake. From Earthquake Engineering Research Laboratory Report 71-23.

RESPONSE SPECTRUM

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST

IIIF088 71.102.0 633 EAST BROADWAY, MUNICIPAL SERVICE BLDG., GLENDALE, CAL. COMP S70E

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL

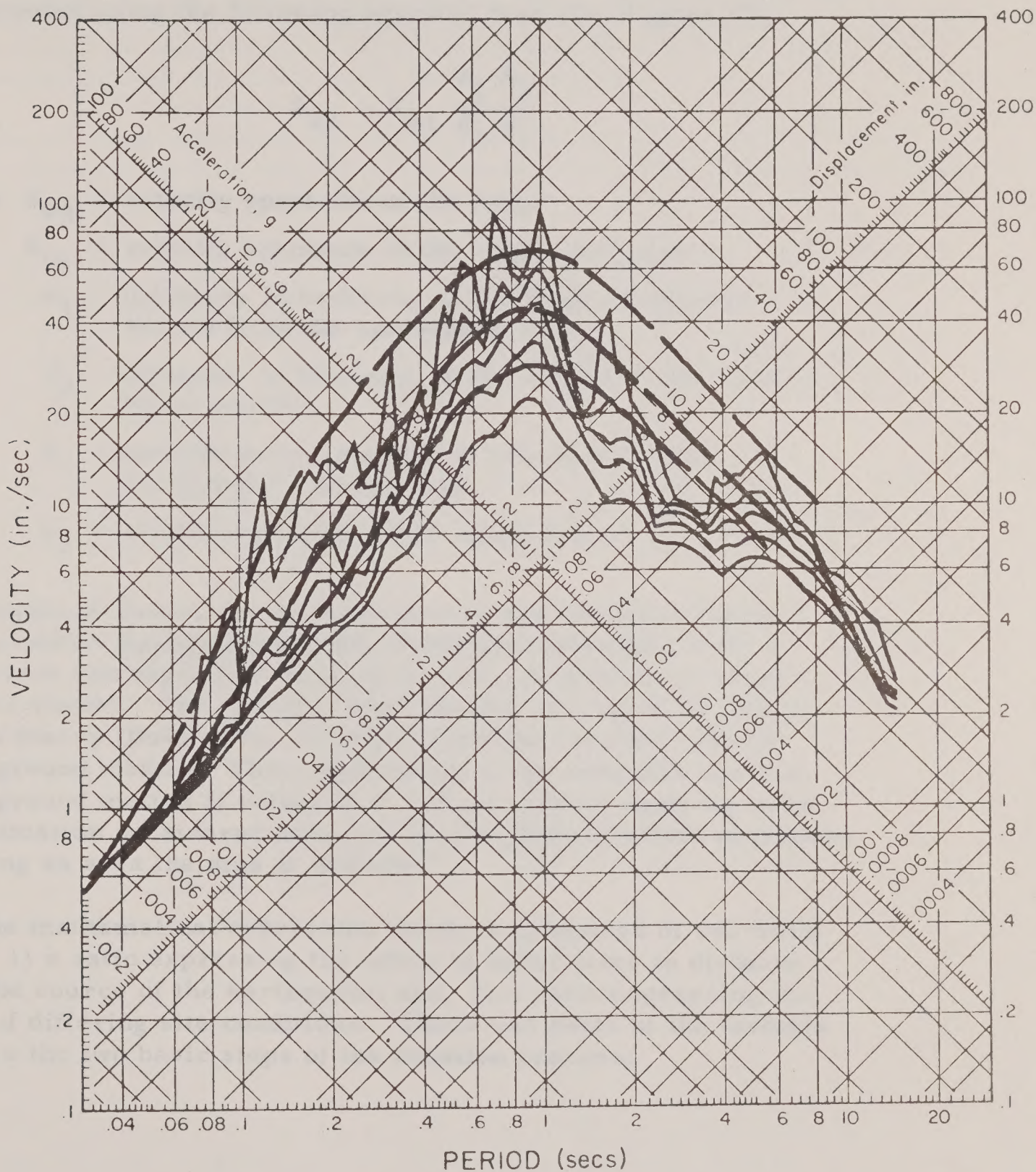


Figure 23. Response spectrum from Glendale site, 1971 San Fernando earthquake. The heavy dashed lines are smoothed envelopes of the two horizontal components for 0, 5 and 10% critical damping. From Earthquake Engineering Research Laboratory Report 73-84.

RESPONSE SPECTRUM

SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0800 PST

STATION 11.102.0 633 EAST BROADWAY, MONITORIAL SERVICE BLDG., ALHAMBRA, CALIF. 91801

GRAPHING VALUES ARE 0.25 IN AND 20 PERCENT IN CRITICAL

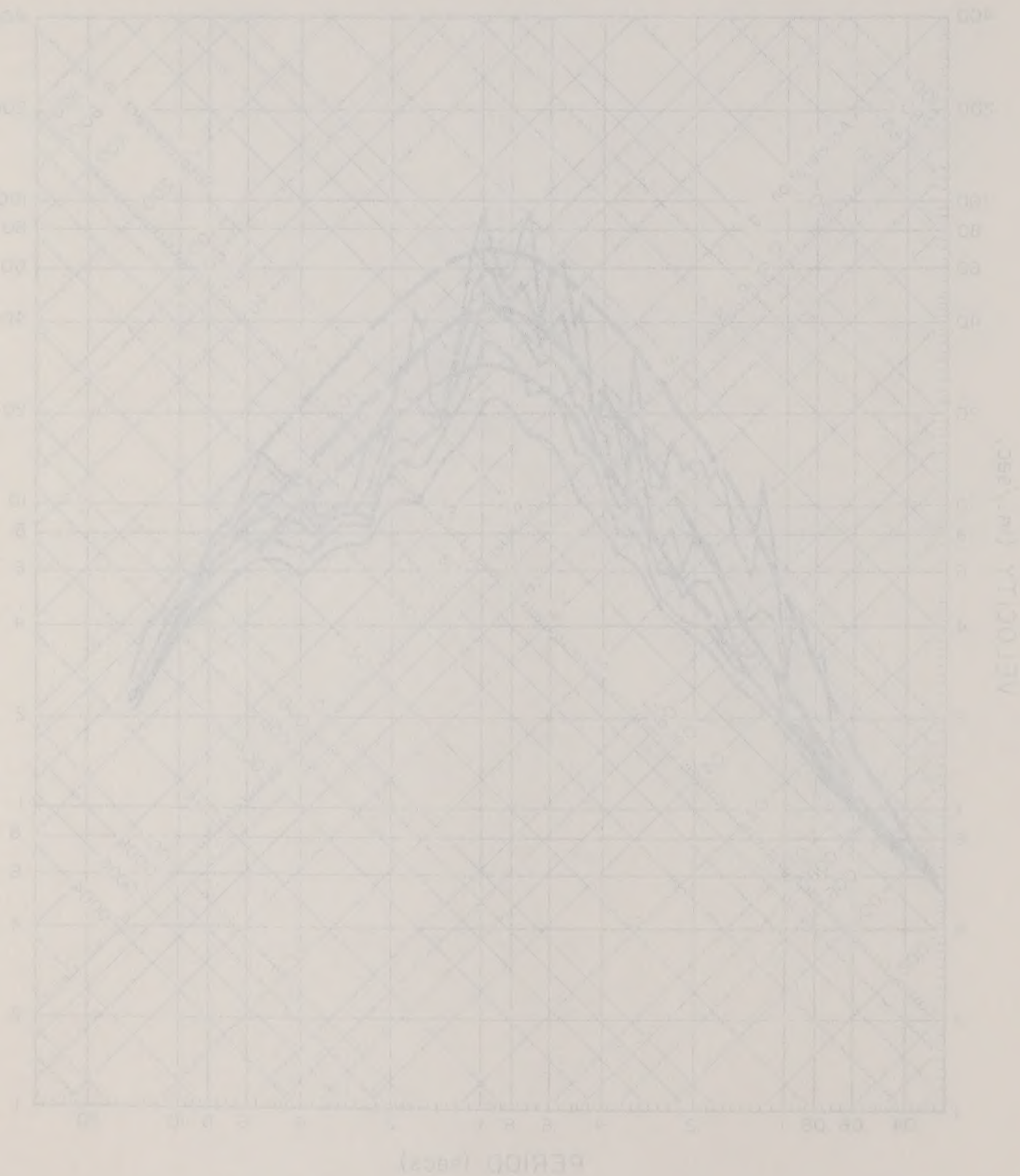


Figure 5.1. Response spectrum from Chino site, 1971 San Fernando earthquake. The heavy dashed line is smoothed envelope of the two horizontal components for 5 and 10% critical damping. From Earthquake Engineering Research Laboratory Report 73-84.

d. Microzonation

1) Methodology

The spectrum of the ground motion at a site within the City can be computed using the following equation (see also Figure 19):

$$S_{V2} = S_{V1} \frac{d_1 A_2}{d_2 A_1}$$

where: S_{V2} = velocity spectrum at the site,

S_{V1} = velocity spectrum of the "type earthquake",

d_1 = distance, in bedrock, of the "type earthquake" record from the earthquake source,

d_2 = distance, in bedrock, of the site from the earthquake source,

A_1 = amplification spectrum of site of the "type earthquake" record, and

A_2 = amplification spectrum of the site.

In the equation above, the distance factors are simplified from a more complex equation assuming cylindrical spreading from a line source and negligible damping in bedrock (granite or metamorphic rocks). The spectral relationships are based on linear system theory (Duke et al, 1970) valid for the Fourier spectra of the ground motion. Their application to the response spectra of the ground motion at values of 0-10% of critical damping is an approximation considered adequate for the generalization necessary in zoning an area the size of Burbank.

The mathematical expression above is composed of two basic parts: 1) a ratio expressing the effect of differences in distance from the source of the earthquake; and, 2) a ratio expressing the effect of differing site conditions. These two parts of the formula are also the two basic steps of the zonation process.

1) Methodology

The spectrum of the ground motion at a site within the CNY can be computed using the following equation (see also Figure 19)

$$S_{VS} = S_{V1} \frac{b_1 A_1}{b_2 A_2}$$

where: S_{VS} = velocity spectrum at the site;
 S_{V1} = velocity spectrum of the "type earthquake";
 b_1 = distance, in bedrock, of the "type earthquake" record from the earthquake source;
 b_2 = distance, in bedrock, of the site from the earthquake source;
 A_1 = amplification spectrum of site of the "type earthquake" record; and
 A_2 = amplification spectrum of the site.

In the equation above, the distance factors are simplified from a more complex equation assuming cylindrical spreading from a line source and negligible damping in bedrock (Kramer or Neftci-morphic code). The spectral relationships are based on linear system theory (Kramer et al., 1979) valid for the Fourier spectra of the ground motion. Their application to the response spectra of the ground motion at values of 0.1% of critical damping is an approximation considered adequate for the generalization necessary in zoning an area the size of Burbank.

The mathematical expression above is composed of two basic parts: 1) a ratio expressing the effect of differences in distance from the source of the earthquake; and, 2) a ratio expressing the effect of differing site conditions. These two parts of the formula are also the two basic steps of the zonation process.

2) Zone Boundaries

Zone boundaries at Burbank are based primarily on site conditions. The northeastern part of the City designated Zone II, is underlain by hard igneous and metamorphic rocks. Its distance to the source fault (Sierra Madre) ranges from 2.5 up to about 4 miles, but since existing and potential development is concentrated along the toe of the mountains the distance factor for this zone is taken at 4 miles.

Zone V is located immediately adjacent to the toe of the mountains, and is characterized by thin alluvium, up to about 200 feet thick, overlying hard bedrock. Its distance to the source fault is about 4.5 miles.

The major part of the City is located in the eastern part of the San Fernando Valley proper, and on a relatively thick alluvial section similar to the Glendale accelerograph site. Since the distance to the source fault ranges from 4.5 to 9 miles, this area is arbitrarily divided into 2 zones, 4.5 to 6 miles from the source (Zone IV) and 6 to 9 miles from the fault (Zone I).

Zone III involves a relatively small part of the extreme southern part of the City in which thin alluvium (less than 200 feet) is underlain by sedimentary and basement rocks. The areal distribution of these zones is shown on Plate I.

3) Shaking Characteristics for Zones

The response spectra for the five zones have been calculated from the smoothed envelopes of the Glendale spectrum using the equation developed in Figure 19 and the following site parameters:

<u>Zone</u>	<u>Distance (d_2) in Miles</u>	<u>Amplification Factor for Range of Period in Seconds (A_2)</u>		
		<u>0-0.4</u>	<u>0.4-1.8</u>	<u>1.8-4.0</u>
II	4	3	2	2
V	4.5	12	3	3
IV	5.5	6	6	4.5
I	7.5	6	6	4.5
III	9	9	4.5	4.5
Glendale	13 (d_1)	6 (A_1)	6 (A_1)	4.5 (A_1)

Zone boundaries as shown are based primarily on site conditions. The northeastern part of the City designated Zone II, is underlain by hard basalt and metamorphic rocks. Its distance to the source is about 4 miles. The distance to the source is about 4 miles, but since existing historic hazard ranges from 1.5 to 2 miles, the distance to the source and potential development is concentrated along the toe of the mountain. The distance factor for this zone is taken as 4 miles.

Zone V is located immediately adjacent to the toe of the mountain and is characterized by this situation. It is about 500 feet below, overlying hard basalt. Its distance to the source is about 2.5 miles.

The major part of the City is located in the western part of the San Fernando Valley proper, and on a relatively flat alluvial section adjacent to the Glendale alluvial fan. Since the distance to the source is about 5 to 9 miles, this area is relatively divided into 2 zones. 4.5 to 6 miles from the source (Zone I) and 6 to 9 miles from the fault (Zone II).

Zone III involves a relatively small part of the extreme southern part of the City in which this situation (less than 500 feet) is underlain by sedimentary and basement rocks. The exact distribution of these zones is shown on Plate I.

3. Station Characteristics for Zones

The response spectra for the five zones have been calculated from the assumed envelopes of the Glendale spectrum using the equations developed in Figure 19 and the following site parameters:

Zone	Distance (mi) to Miles	Amplification factor for Range of Period in Seconds (s)		
		0.5-1.0	1.0-1.5	1.5-2.0
II	4	1	2	3
V	4.5	1.5	3	4
IV	5.5	2	4	5.5
I	7.5	3	5	7.5
III	9	4	6.5	10
Glendale	11 (mi)	5 (A ₁)	8 (A ₂)	12 (A ₃)

The resulting spectra are included as Figures 24 through 28, and the generalized shaking characteristics (maximum ground acceleration, predominant period, and duration of "strong" shaking) are summarized in Table 6.

TABLE 6. GENERALIZED CHARACTERISTICS OF EXPECTED EARTHQUAKE SHAKING AT BURBANK

Zone	Maximum Ground Acceleration (Gravity)	Predominant Period (seconds)	Duration of Strong Shaking (seconds)
I	0.45	0.3-0.5	10-15
II	0.5	0.2-0.4	8-10
III	0.55	0.2-0.3	10-12
IV	0.55	0.3-0.5	10-15
V	0.7	0.2-0.3	10-12

4) Comparison of Predicted and Observed Shaking

Studies of observed shaking of sufficient detail to allow a comparison with predicted shaking are not available for Burbank. However, a detailed study of damage factors and variations in shaking for two areas in western Glendale by Scholl (1974) tends to confirm the approximate level and relative variation in the derived spectra. Of particular significance is Scholl's observation that damage in the area of thin alluvium between Glenoaks Boulevard and the toe of the mountains was about twice that in an area south of the Glendale Freeway. The former would be a near equivalent to Burbank Zone V (most severe predicted shaking) while the latter would compare with Burbank Zones I and III (lowest to intermediate predicted shaking).

D. SECONDARY HAZARDS

1. Settlement

Settlement may occur in poorly consolidated soils during earthquake shaking as the result of a more efficient rearrangement of the individual grains. Settlement of sufficient magnitude to cause significant structural damage are normally associated with rapidly deposited alluvial soils, or improperly founded or poorly compacted

The resulting spectra are included as Figures 14 through 16, and the generalized shaking characteristics (maximum ground acceleration, predominant period, and duration of 'strong' shaking) are summarized in Table 6.

TABLE 6. GENERALIZED CHARACTERISTICS OF EXPECTED EARTHQUAKE SHAKING AT BURBANK

Zone	Maximum Ground Acceleration (G-level)	Predominant Period (seconds)	Duration of Strong Shaking (seconds)
I	0.45	0.3-0.8	10-15
II	0.5	0.3-0.8	8-10
III	0.55	0.3-0.8	10-15
IV	0.55	0.3-0.8	10-15
V	0.5	0.3-0.8	10-15

4. Classification of Predicted and Observed Shaking

Studies of observed shaking of sufficient detail to allow a comparison with predicted shaking are not available for Burbank. However, a detailed study of damage factors and variations in shaking for two sites in western Glendale by Scholl (1974) tends to confirm the approximate level and relative variation in the derived spectra. Of particular significance is Scholl's observation that damage in the area of this alignment between Chomberg Boulevard and the toe of the mountains was about twice that in an area south of the Glendale Freeway. The former would be a near equivalent to Burbank Zone V (most severe predicted shaking) while the latter would compare with Burbank Zones I and II (least to intermediate predicted shaking).

D. SECONDARY HAZARDS

1. Settlement

Settlement may occur in poorly consolidated soils during earth quake shaking as the result of a more efficient rearrangement of the individual grains. Settlement of sufficient magnitude to cause significant structural damage are normally associated with heavily deposited alluvial soils, or heterogeneously founded or poorly consolidated

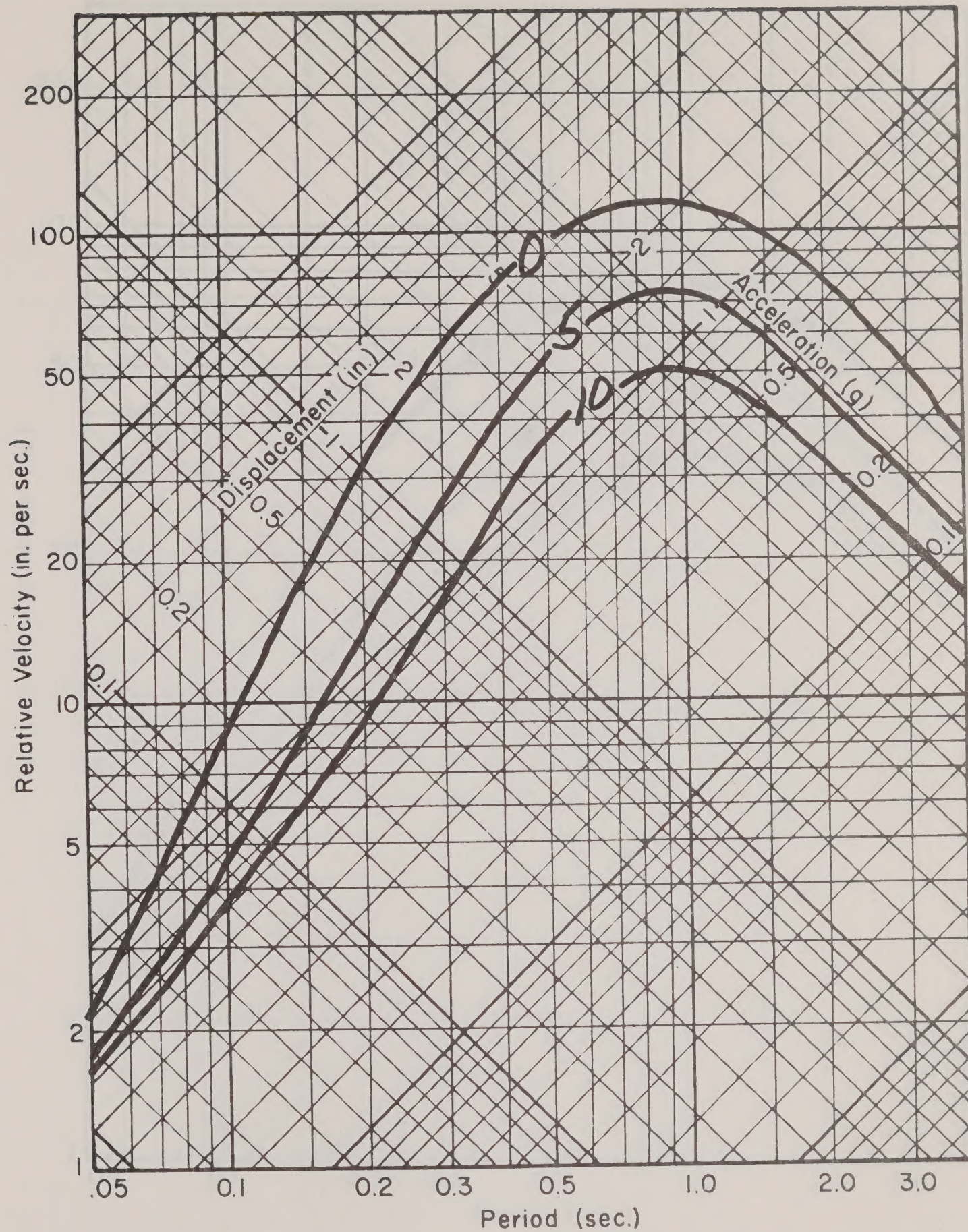


Figure 24. Response spectrum, Zone I for 0, 5, and 10% critical damping.

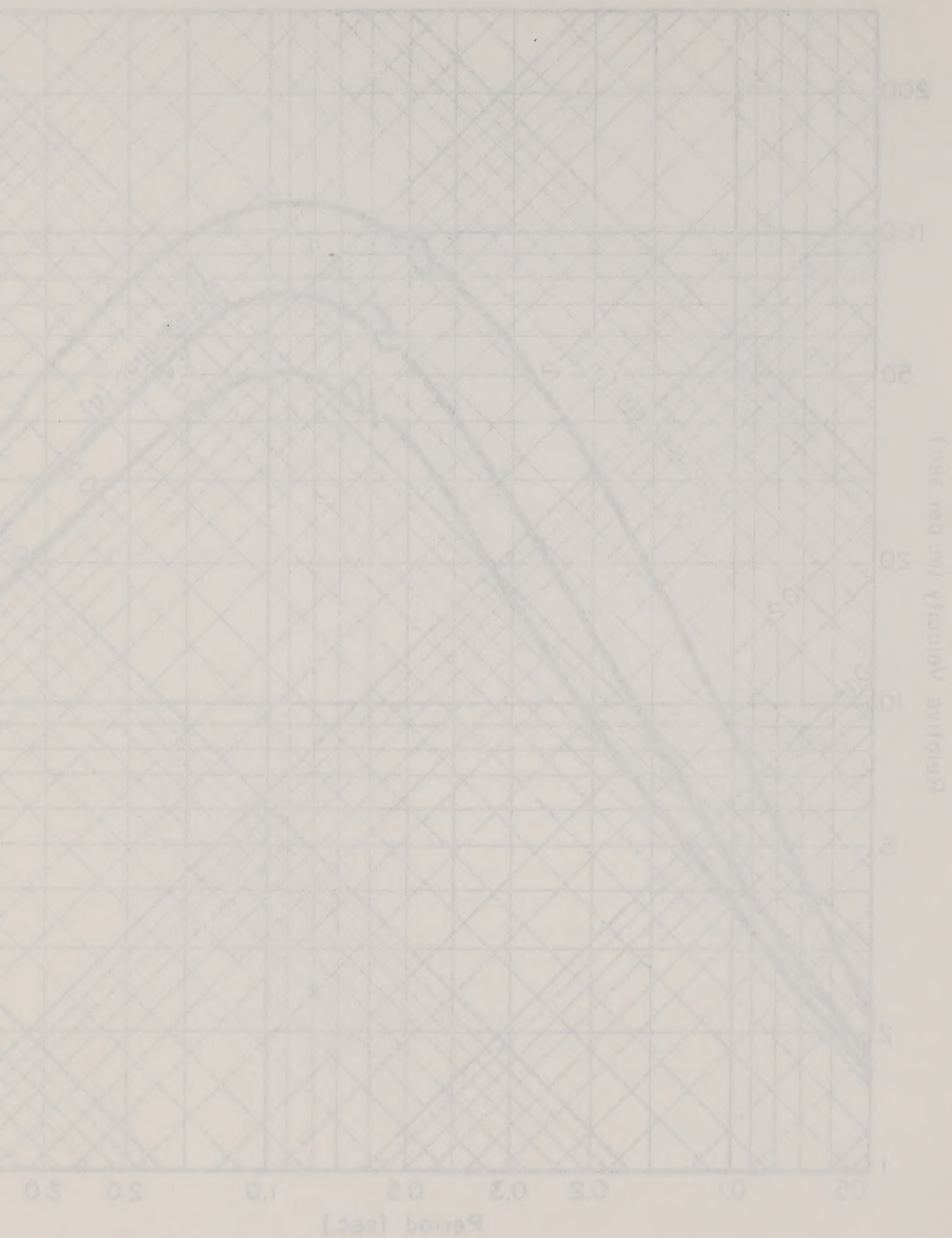


Figure 24. Response spectrum, Zone I for 0, 5, and 10% critical damping.

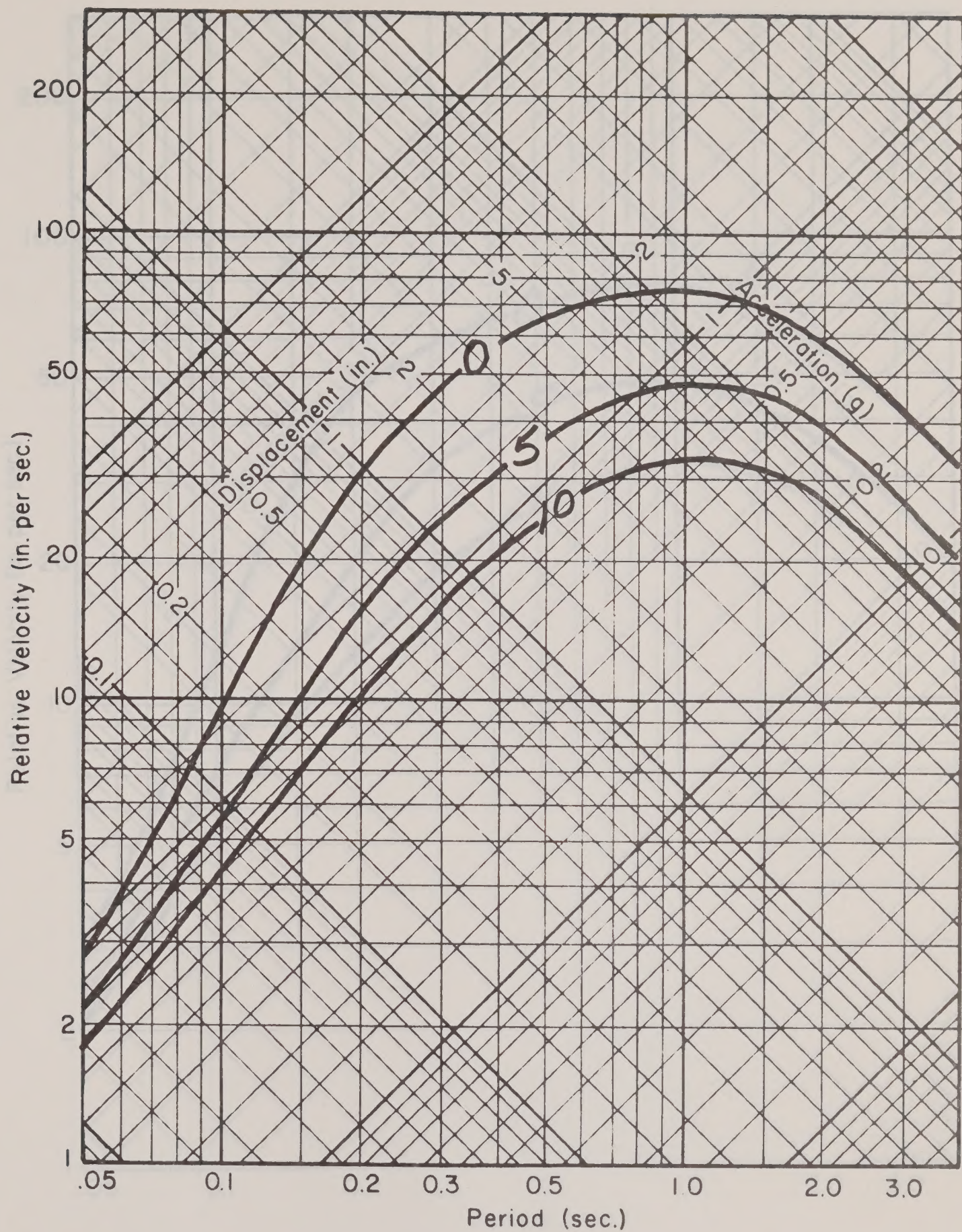


Figure 25. Response spectrum, Zone II for 0, 5, and 10% critical damping.

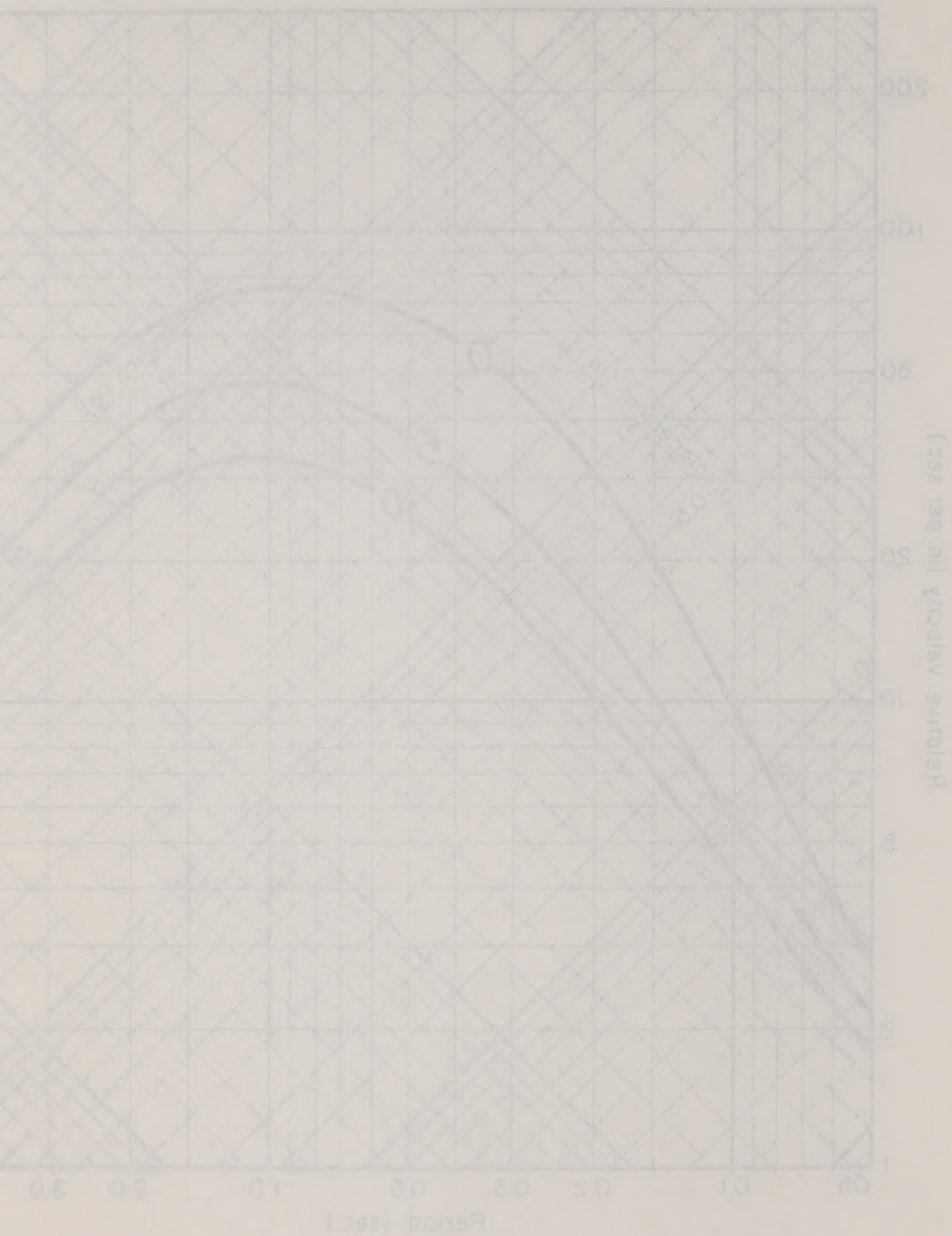


Figure 55. Response curves for Zone II for 0.5, 2, and 10% elliptical bending.

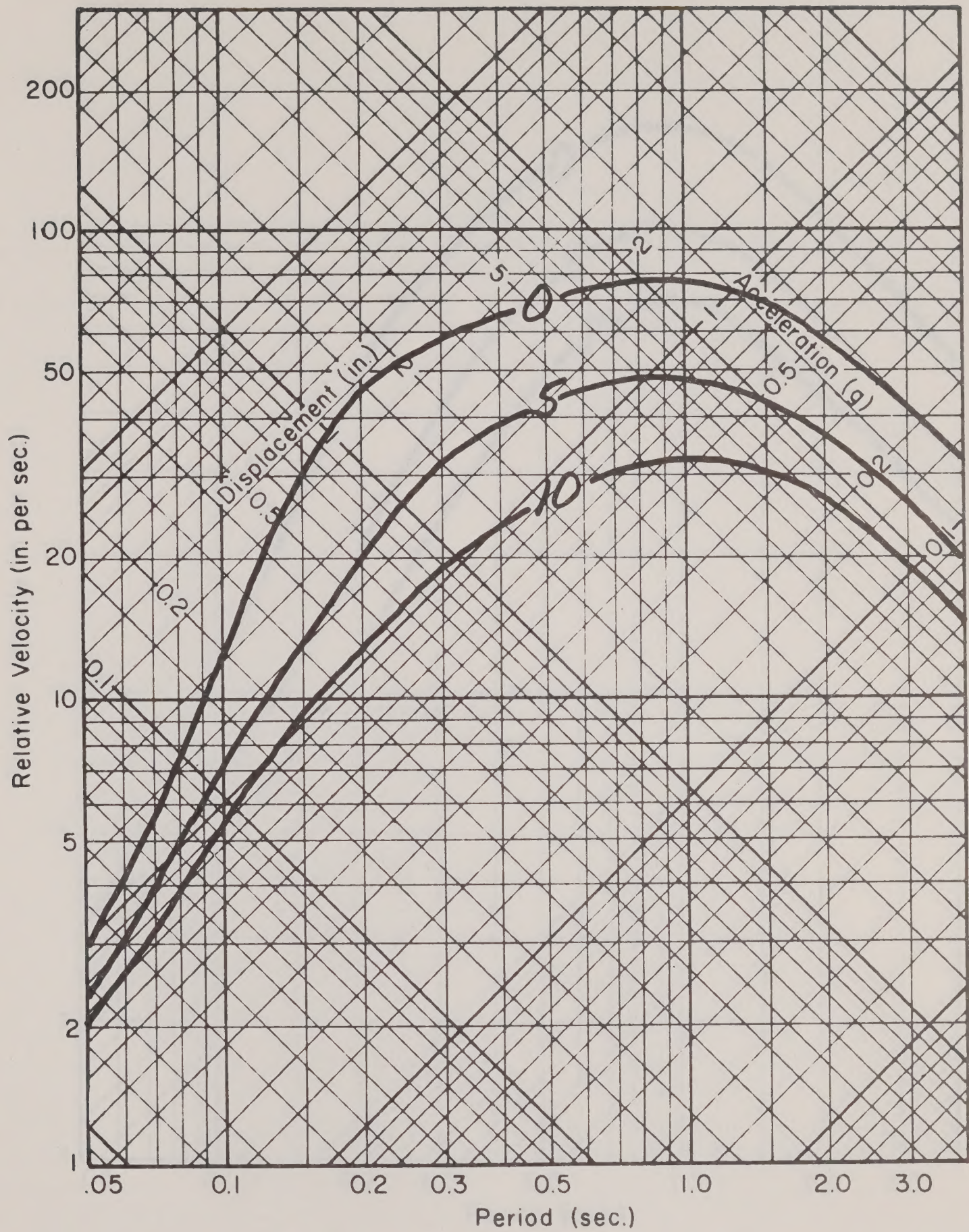


Figure 26. Response spectrum, Zone III for 0, 5, and 10% critical damping.

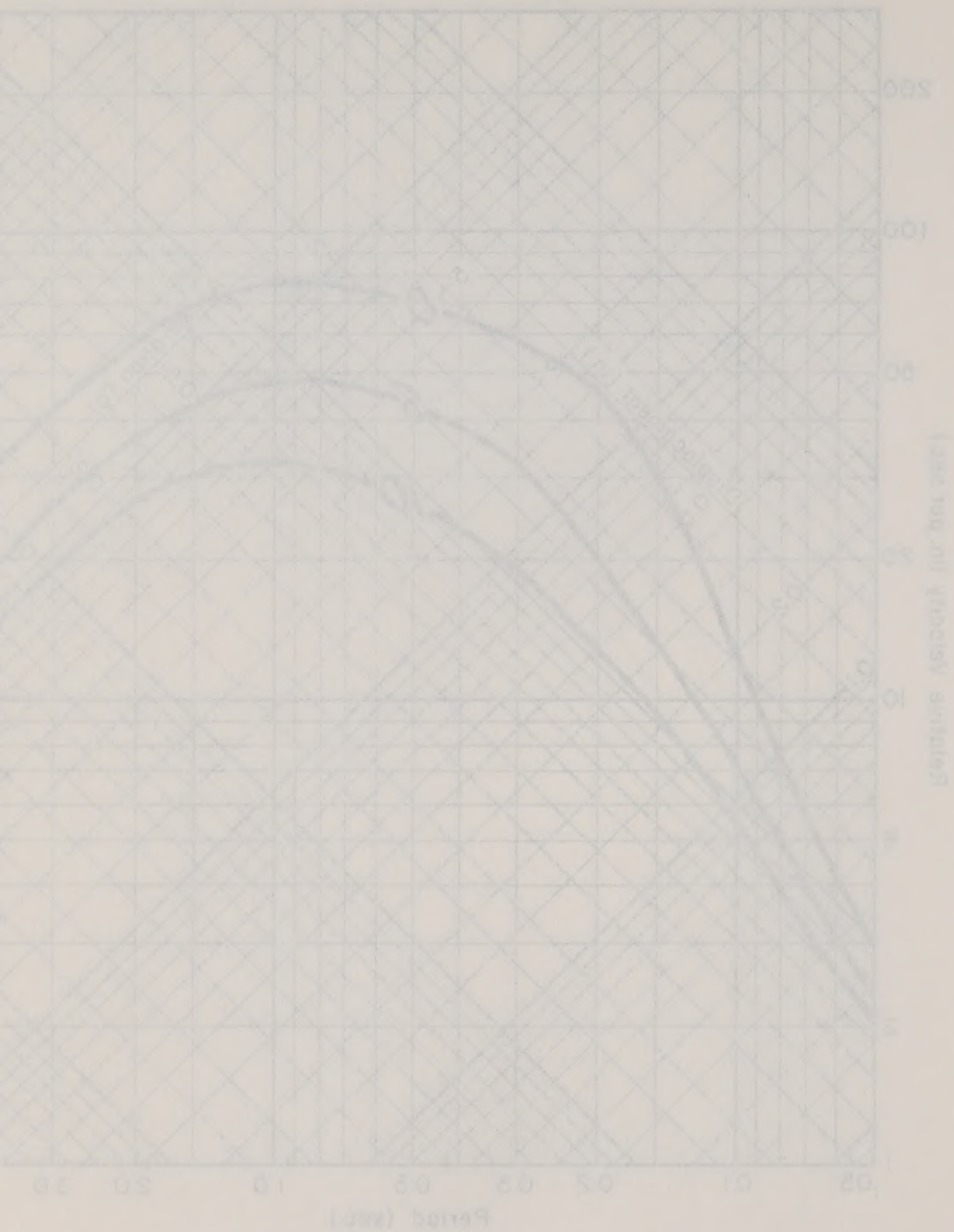


Figure 5b. Response spectrum, zone III for 0.5, 1, 2, and 5% critical damping.

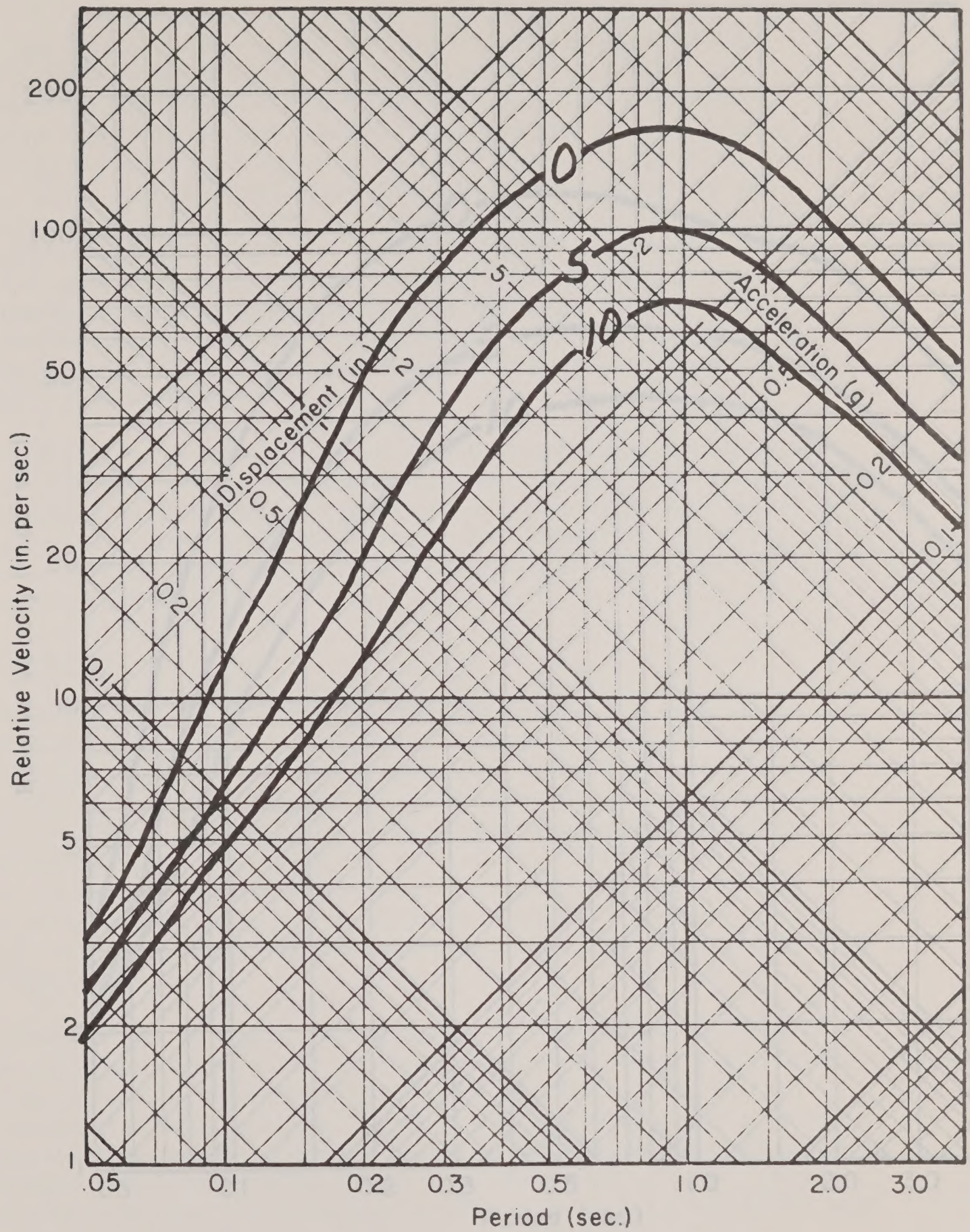


Figure 27. Response spectrum, Zone IV for 0, 5, and 10% critical damping.

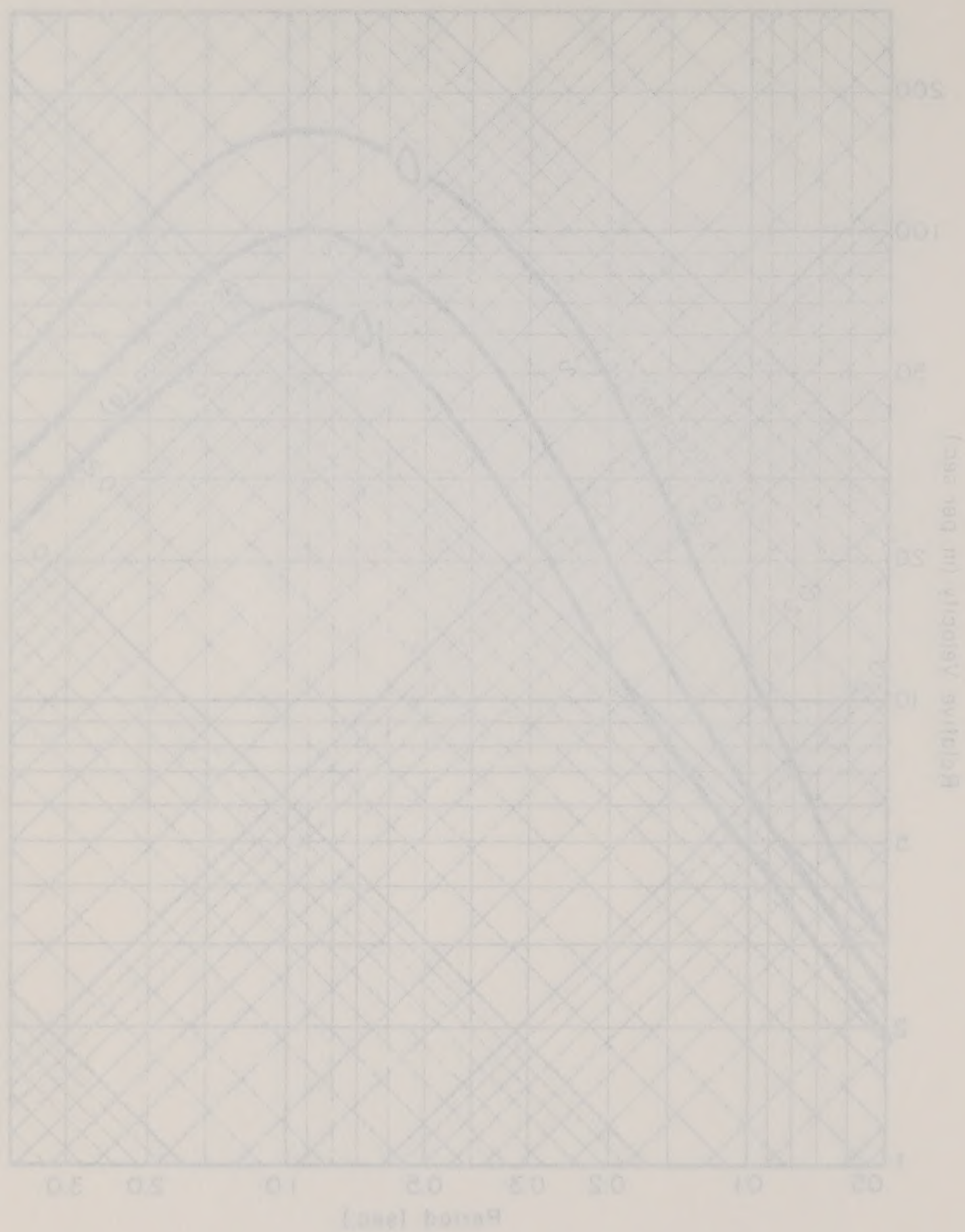


Figure 57. Response spectrum, Zone IV for 0, 5, and 10% critical damping.

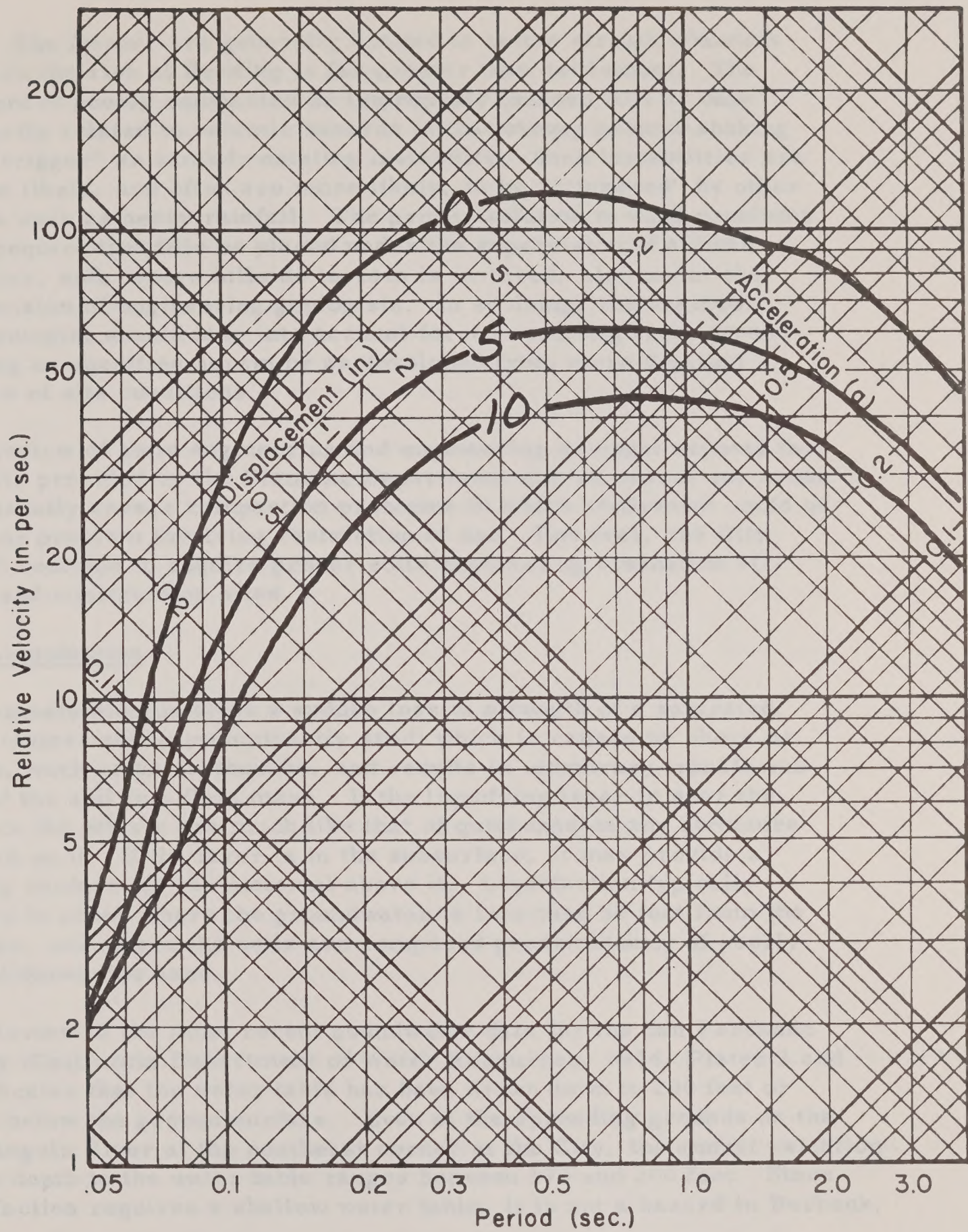


Figure 28. Response spectrum, Zone V for 0, 5, and 10% critical damping.

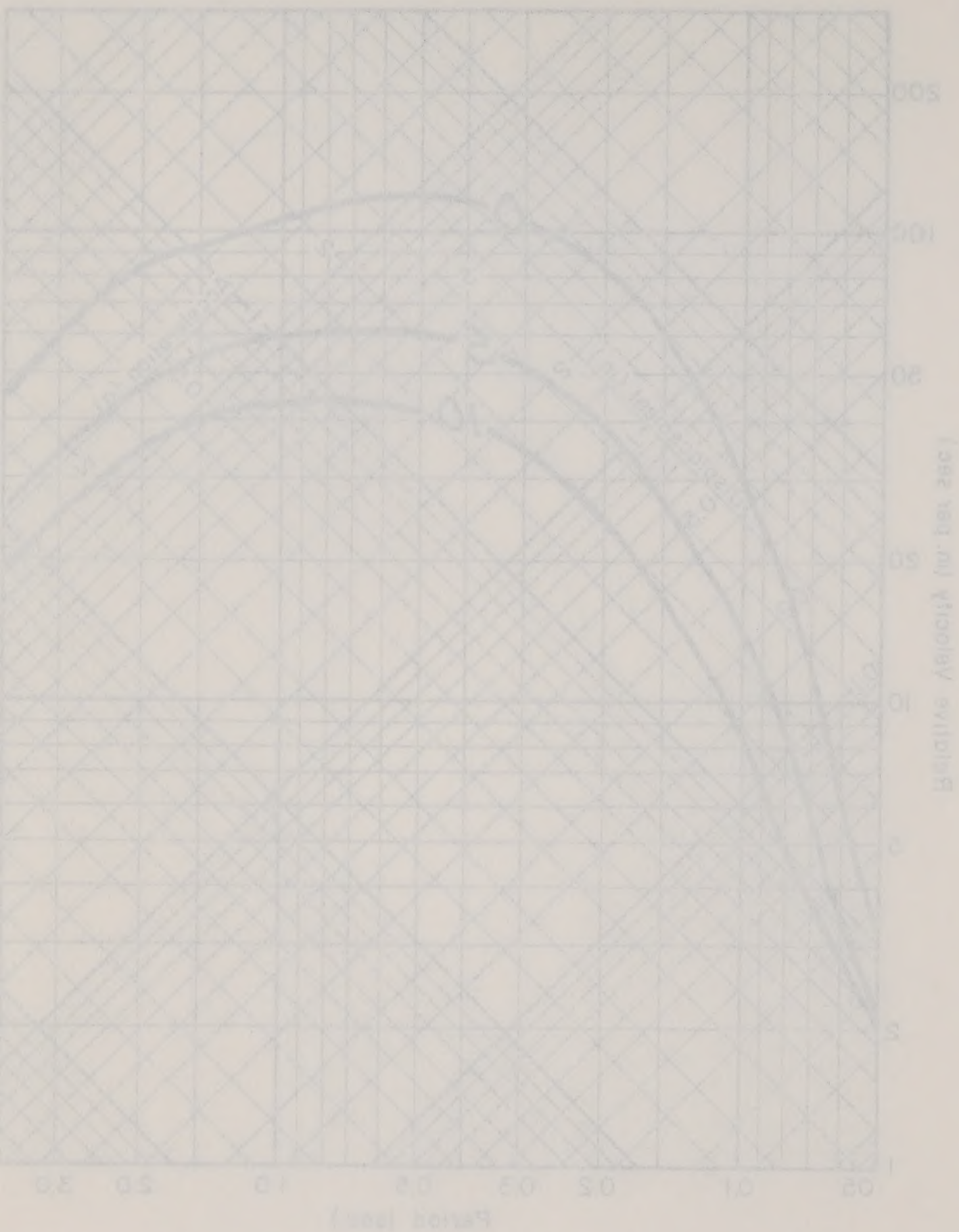


Figure 58. Response spectrum, Zone V for 0, 5, and 10% critical damping.

fills. The former are generally limited to active stream channels in which the risk of flooding is far greater than settlement. The problem of poorly compacted or improperly founded fills is only indirectly related to seismic hazards in that strong ground-shaking may "trigger" an already existing instability. Such instabilities are just as likely, and often are more likely, to be "triggered" by other events such as heavy rainfall. The proper solution to such problems is to require that fills be placed under the supervision of a soils engineer, and, where hillside terrain is involved, also under the supervision of engineering geologists. In so doing, the engineer and geologist should take into account forces resulting from ground-shaking as specified herein or as developed from more detailed studies of site conditions.

Review of soils engineering and engineering geologic reports for the City provided by the Planning Department did not reveal any areas of unusually severe compaction problems in which settlement could be a major problem involving restriction of use. However, the City should continue to require proper soils engineering evaluation of proposed construction sites.

2. Liquefaction

Liquefaction involves a sudden loss in strength of a saturated, cohesionless soil (predominantly sand) which is caused by shock or strain, such as an earthquake, and results in temporary transformation of the soil to a fluid mass. If the liquefying layer is near the surface the effects are much like that of quicksand on any structure located on it. If the layer is in the subsurface, it may provide a sliding surface for the material above it. Liquefaction typically occurs in areas where the groundwater is less than 30 feet from the surface, and where the soils are composed predominantly of poorly consolidated fine sand.

Review of the most recent groundwater data for the San Fernando Valley (California Department of Water Resources, 1974, Plates 3 and 4) indicates that the water table has been drawn down to 200 feet or more below the ground surface. Even at the spreading grounds on the Los Angeles River at the southeast corner of the City, the annual variation in the depth to the water table ranges between 175 and 200 feet. Since liquefaction requires a shallow water table, it is not a hazard in Burbank.

fills. The former are generally limited to active stream channels in which the risk of flooding is far greater than settlement. The problem of poorly compacted or improperly founded fills is only indirectly related to seismic hazards in that strong ground shaking may "trigger" an already existing instability. Such instabilities are just as likely, and often are more likely, to be "triggered" by other events such as heavy rainfall. The proper solution to such problems is to require that fills be placed under the supervision of a soils engineer, and, where fillside failure is involved, also under the supervision of engineering geologists. In so doing, the engineer and geologist should take into account forces resulting from ground shaking as specified herein or as developed from more detailed studies of site conditions.

Review of soils engineering and engineering geologic reports for the City provided by the Planning Department did not reveal any areas of unusually severe compaction problems in which settlement could be a major problem involving restriction of use. However, the City should continue to require proper soils engineering evaluation of proposed construction sites.

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Review of the most recent groundwater data for the San Fernando Valley (California Department of Water Resources, 1974, Plates 3 and 4) indicates that the water table has been drawn down to 200 feet or more below the ground surface. Even at the spreading grounds on the Los Angeles River at the southern extent of the City, the annual variation in the depth to the water table ranges between 175 and 200 feet. Since liquefaction requires a shallow water table, it is not a hazard in Burbank.

3. Landslides

Landslides should be considered a basic geologic hazard rather than one having an unusual association with earthquakes. The shaking of an earthquake only provides the triggering force to initiate downslope movement of a previously unstable earthmass. The prime factor is the unstable condition itself. Movement could just as easily be triggered by heavy rains, or by grading on a construction project.

Areas of slope sufficiently steep to be considered for their landslide potential are limited to the Verdugo Mountains. Rocks in this area are hard igneous and metamorphic types with complex jointing, foliation, and other types of rock weaknesses that could control landsliding. This area was studied using stereoscopic pairs of aerial photographs (Fairchild 6630-96 through 100, October 6, 1940, and LIA, L2, and L2A, no date) without locating any natural landslides of significant size. A large slide appears to be present in an unnamed tributary of La Tuna Canyon, but it is north of the City boundary. Natural landslides are, therefore, considered a relatively minor problem in Burbank. Landslides, however, may also occur as the result to grading for construction if the natural support of the weaker planes within the rock is removed. The City should, therefore, continue to require engineering geologic evaluation and control of grading in hillside areas.

E. TSUNAMIS AND SEICHES

Tsunamis are seismic sea waves, and do not present a hazard at Burbank.

Seiches are standing waves produced in a body of water by the passage of seismic waves from an earthquake. Seiches are not a significant hazard because of the absence of lakes or reservoirs of significant size within the City.

F. SEISMIC/GEOLOGIC RISK RATING (Major Conclusions and Recommendations)

Seismic/geologic risk rating in the City of Burbank is presented in the form of a matrix and a map showing the distribution of the zones having different hazards or different levels of risk associated with those hazards. Land use recommendations are also related to these zones within the matrix. The land use categories are broken down into three major groupings; "L" for Limited Occupancy; "N" for Normal Occupancy, and "C" for Critical Facilities. The matrix is included as Table 7, and the map is Plate I. A listing of facilities that would be represented under each of these groups is shown in Table I.

The contents of the matrix are the major conclusions and recommendations of this study. They are:

Landslides should be considered a basic geologic hazard rather than one having an unusual association with earthquakes. The sliding of an earthquake only provides the triggering force to initiate downslope movement of a previously unstable earthmass. The prime factor is the unstable condition itself. Movement could just as easily be triggered by heavy rains, or by grading or a construction project.

Areas of slope sufficiently steep to be considered for their landslide potential are limited to the Vashito Mountains. Rocks in this area are hard igneous and metamorphic types with complex jointing, foliation, and other types of rock weaknesses that could control landsliding. This area was studied using stereoscopic pairs of aerial photographs (P-100-90 through 100, October 6, 1940, and 100-91, and 100-92, no date) without locating any natural landslides or significant ones. A large slide appears to be present in an unnamed tributary of La Tuna Canyon, but it is north of the City boundary. Natural landslides are, therefore, considered a relatively minor problem in Burbank. Landslides, however, may also occur as the result of grading for construction if the natural support of the weaker planes within the rock is removed. The City should, therefore, continue to require engineering geologic evaluation and control of grading in hillside areas.

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The contents of the matrix are the major conclusions and recommendations of this study. They are:

1. Strong shaking in the event of a major earthquake on the Sierra Madre fault near La Crescenta is the primary seismic risk at Burbank. The basic framework of the risk rating matrix is, therefore, the microzonation for ground shaking.
2. The Verdugo fault is considered potentially active. Future ground rupture along the trace of the fault is not expected, but the possibility cannot be completely dispelled. The construction of critical or important facilities (i. e. hospitals, schools, etc.) along the exposed or buried trace of the fault should be discouraged. A thorough evaluation of this fault in the subsurface should be undertaken if such facilities are proposed in this zone.
3. Secondary hazards such as differential settlement and liquefaction are not considered a significant problem in Burbank and are not included in the matrix. However, the City should continue to require soils engineering investigations as a part of proper construction procedure.
4. Natural landslides are not a significant problem at Burbank, but grading in hillside areas could result in the creation of unstable slopes. Therefore, the City should continue to require engineering geologic investigations in hillside areas.
5. Tsunamis and seiches are not considered a significant seismic hazard at Burbank, and are not included in the matrix.

TABLE 7. SEISMIC/GEOLOGIC RISK RATING MATRIX

Zone	Maximum Ground Acceleration (Gravity)	Site Investigations Recommended		
		Soils Engineering	Engineering Geologic	Fault Evaluation
I	0.45	L, N, C		
II	0.5	L, N, C	L, N, C	
III	0.55	L, N, C		
IV	0.55	L, N, C		
V	0.7	L, N, C	L, N, C	
VA	0.7	L, N, C	L, N, C	N, C

L = Limited occupancy; N = Normal occupancy; C = Critical facilities.

1. Strong shaking in the event of a major earthquake on the Sierra Madre fault near La Cresswell is the primary seismic risk at Burbank. The basic framework of the risk rating matrix is, therefore, the interpretation for ground shaking.
2. The Verdugo fault is considered potentially active. Future ground rupture along the trace of the fault is not expected, but the possibility cannot be completely dispelled. The consideration of critical or important facilities (i.e., hospitals, schools, etc.) along the exposed or buried trace of the fault should be discouraged. A thorough evaluation of this fault in the subsurface should be undertaken if such facilities are proposed in this zone.
3. Secondary faults such as differential settlement and liquefaction are not considered a significant problem in Burbank and are not included in the matrix. However, the City should continue to require soils engineering investigations as a part of proper construction procedures.
4. Natural landfills are not a significant problem at Burbank, but grading or hillside areas could result in the creation of unstable slopes. Therefore, the City should continue to require engineering geologic investigations in hillside areas.
5. Tectonics and seiches are not considered a significant seismic hazard at Burbank, and are not included in the matrix.

TABLE 1. SEISMIC/GEOLOGIC RISK RATING MATRIX

Zone	Maximum Ground Acceleration (Gravity)	Site Investigations Recommended	
		Soils Engineering	Engineering Geologic
I	0.45	L, N, C	
II	0.5	L, N, C	L, N, C
III	0.55	L, N, C	
IV	0.55	L, N, C	
V	0.7	L, N, C	L, N, C
VA	0.7	L, N, C	L, N, C

L = Limited occupancy; N = Normal occupancy; C = Critical facilities.

TABLE 8

LIMITED OCCUPANCY BUILDINGS

Warehouses
Automated manufacturing
Small commercial

NORMAL OCCUPANCY BUILDINGS

Single family residential
Multiple family residential
Major commercial (department stores, etc.)
Churches and other places of worship
Theaters
Hotels and motels
Office buildings
Medical clinics
Restaurants
Manufacturing facilities and industrial buildings

CRITICAL FACILITIES

Electrical substations
Schools
Fire stations
Railroad lines
City buildings
Hospitals
Sewage treatment plants
Water works
Radio stations
Television stations
Microwave stations
Sheriff/Police offices
Major highways/bridges

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Small commercial

NORMAL OCCUPANCY BUILDINGS

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Restaurants
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CRITICAL FACILITIES

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Schools
Fire stations
Railroad lines
City buildings
Hospitals
Sewage treatment plants
Water works
Radio stations
Television stations
Microwave stations
Navy/Police offices
Major highways/bridges

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APPENDIX

Glossary of Terms

Appendix - A collection of supplementary material, such as maps, photographs, and other documents, that are related to the main text of a report or book. (AGL, 1972)

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Black Clay - A material that is composed of fine-grained, dark-colored soil or sediment. It is often found in the coastal areas of the United States and is characterized by its dark color and fine texture. (AGL, 1972)

Coastal - Situated near or on the coast. (AGL, 1972)

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APPENDIX
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Active Fault — One that has moved in recent geologic time and which is likely to move again in the relatively near future. Definitions for planning purposes extend on the order of 10,000 years or more back and 100 years or more forward.

Alluvial — Pertaining to or composed of alluvium, or deposited by a stream or running water. (AGI, 1972)

Alluvium — A general term for clay, silt, sand, gravel or similar unconsolidated detrital material deposited during comparatively recent geologic time by a stream or other body of running water as a sorted or semisorted sediment in the bed of the stream or on its flood plain or delta, or as a cone or fan at the base of a mountain slope. (AGI, 1972)

Amplification — Elaboration; augmentation; addition (Webster). As used herein, near-surface amplification is the augmentation of wave amplitude resulting from the change in physical properties in near-surface layers (see Introduction).

Amplitude — The extent of the swing of a vibrating body on each side of the mean position. (Webster)

Block Glide — A translational landslide in which the slide mass remains essentially intact, moving outward and downward as a unit, most often along a pre-existing plane of weakness such as bedding, foliation, joints, faults, etc. (AGI, 1972)

Cohesion — Shear strength in a sediment not related to interparticle friction. (AGI, 1972)

Colluvium — (a) A general term applied to any loose, heterogenous, and incoherent mass of soil, material or rock fragments deposited chiefly by mass-wasting, usually at the base of a steep slope or cliff. (b) Alluvium deposited by unconcentrated surface runoff or sheet erosion, usually at the base of a slope. (AGI, 1972)

Compaction — Reduction in bulk volume or thickness of, or the pore space within, a body of fine-grained sediments in response to the increasing weight of overlying material that is continually being deposited, or to the pressure resulting from earth movements within the crust. It is expressed as a decrease in porosity brought about by a tighter packing of the sediment particles. (AGI, 1972)

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Consolidated Material — Soil or rocks that have become firm as a result of compaction.

Damping — The resistance to vibration that causes a decay of motion with time or distance, e.g. the diminishing amplitude of an oscillation. (AGI, 1972)

Differential Settlement — Nonuniform settlement; the uneven lowering of different parts of an engineering structure, often resulting in damage to the structure. (AGI, 1972)

Displacement (Geological) — The relative movement of the two sides of a fault, measured in any chosen direction; also, the specific amount of such movement. Displacement in an apparently lateral direction includes strike-slip and strike separation; displacement in an apparently vertical direction includes dip-slip and dip separation. (AGI, 1972)

Displacement (Engineering) — The geometrical relation between the position of a moving object at any time and its original position. (Webster)

Epicenter — That point on the Earth's surface which is directly above the focus of an earthquake. (AGI, 1972)

Fault — A surface or zone of rock fracture along which there has been displacement, from a few centimeters to a few kilometers in scale. (AGI, 1972)

Fault Surface — In a fault, the surface along which displacement has occurred. (AGI, 1972)

Fault System — Two or more interconnecting fault sets. (AGI, 1972)

Fault Zone — A fault zone is expressed as a zone of numerous small fractures or of heccia or fault gouge. A fault zone may be as wide as hundreds of meters. (AGI, 1972)

Focus (Seism) — That point within the Earth which is the center of an earthquake and the origin of its elastic waves. Syn: hypocenter; seismic focus; centrum (see Introduction). (AGI, 1972)

Ground Response — A general term referring to the response of earth materials to the passage of earthquake vibration. It may be expressed in general terms (maximum acceleration, dominant period, etc.), or as a ground-motion spectrum.

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Hypocenter — See focus.

Intensity (earthquake) — A measure of the effects of an earthquake at a particular place on humans and/or structures. The intensity at a point depends not only upon the strength of the earthquake, or the earthquake magnitude, but also upon the distance from the point to the epicenter and the local geology at the point. (AGI, 1972)

Isoseismal line — A line connecting points on the Earth's surface at which earthquake intensity is the same. It is usually a closed curve around the epicenter. Syn: isoseism; isoseismic line; isoseismal. (AGI, 1972)

Liquefaction — A sudden large decrease in the shearing resistance of a cohesionless soil, caused by a collapse of the structure by shock or strain, and associated with a sudden but temporary increase of the pore fluid pressure. (AGI, 1972)

Macroseismic data — Used herein to describe instrumentally recorded earthquakes generally in the range of Richter magnitude 3.0 or more. (This use differs from the AGI definition of "macro-seismic observations").

Magnitude (earthquake) — A measure of the strength of an earthquake or the strain energy released by it, as determined by seismographic observations. As defined by Richter, it is the logarithm, to the base 10, of the amplitude in microns of the largest trace deflection that would be observed on a standard torsion seismograph (static magnification = 2800; period = 0.18 sec; damping constant = 0.8) at a distance of 100 kilometers from the epicenter. (AGI, 1972)

Microseismic data — Used herein to describe instrumentally recorded earthquakes generally in the range of Richter magnitude 3.0 or less. (This use is consistent with the AGI definition of microseism and microseismometer, but is more restricted than their definition of microseismic data).

Natural period — The period at which maximum response of a system occurs. The inverse of resonant frequency.

Normal fault — A fault in which the hanging wall appears to have moved downward relative to the footwall. The angle of the fault is usually 45-90 degrees. This is dip-separation, but there may or may not be slip. (AGI, 1972)

Hypocenter - See focus.

Intensity (earthquake) - A measure of the effects of an earthquake at a particular place on humans and/or structures. The intensity at a given place not only upon the strength of the earthquake, but the earthquake magnitude, but also upon the distance from the point to the epicenter and the local geology at the point. (AGI, 1975)

Isostatic line - A line connecting points on the Earth's surface at which isostatic intensity is the same. It is usually a closed curve around the epicenter. Syn: isostatic isostatic line, isostatic. (AGI, 1975)

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- Predominant period — The period of the acceleration, velocity or displacement which predominates in a complex vibratory motion. In the analysis of earthquake vibrations, predominant period is normally the period of the maximum amplitude of the acceleration spectrum.
- Response spectrum — An array of the response characteristics of a structure or structures ordered according to period or frequency. The structures are normally single-degree-of-freedom oscillators, and the characteristics may be displacement, velocity or acceleration (see Introduction).
- Seiche — All standing waves on any body of water whose period is determined by resonant characteristics of the containing basin as controlled by its physical dimensions. (U.S. Geol. Survey Prof. Paper 544-E)
- Seismic seiche — Standing waves set up on rivers, reservoirs, ponds and lakes at the time of passage of seismic waves from an earthquake. (U.S. Geol. Survey Prof. Paper 544-E)
- Shear — A strain resulting from stresses that cause or tend to cause contiguous parts of a body to slide relatively to each other in a direction parallel to their plane of contact; specifically, the ratio of the relative displacement of these parts to the distance between them. (AGI, 1972)
- Shear wave or S-wave — That type of seismic body wave which is propagated by a shearing motion of material so that there is oscillation perpendicular to the direction of propagation. It does not travel through liquids. (AGI, 1972)
- Slip — On a fault, the actual relative displacement along the fault plane of two formerly adjacent points on either side of the fault. Slip is three dimensional, whereas separation is two dimensional. (AGI, 1972)
- Strike-slip fault — A fault, the actual movement of which is parallel to the strike (trend) of the fault. (AGI, 1972)
- Subsidence — A local mass movement that involves principally the gradual downward settling or sinking of the solid Earth's surface with little or no horizontal motion and that does not occur along a free surface (not the result of a landslide or failure of a slope. (AGI, 1972)

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Tectonic — Of or pertaining to the forces involved in, or the resulting structures or features of the upper part of the Earth's crust. (mod. from AGI, 1972)

Tsunami — A gravitational sea wave produced by any large-scale, short-duration disturbance of the ocean floor, principally by a shallow submarine earthquake, but also by submarine earth movement, subsidence, or volcanic eruption, characterized by great speed of propagation (up to 950 km/hr.), long wavelength (up to 200 km.), long period (5 min. to a few hours, generally 10 - 60 min.), and low observable amplitude on the open sea, although it may pile up to great heights (30 m. or more) and cause considerable damage on entering shallow water along an exposed coast, often thousands of kilometers from the source. (AGI, 1972)

Unconsolidated material — A sediment that is loosely arranged or unstratified or whose particles are not cemented together, occurring either at the surface or at depth. (AGI, 1972)

Water table — The surface between the zone of saturation and the zone of aeration; that surface of a body of unconfined ground water at which the pressure is equal to that of the atmosphere. (AGI, 1972)

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Tsunami - Of or pertaining to the forces involved in
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Tsunami - A gravitational sea wave produced by any large-scale, abrupt
 deflection of the ocean floor, principally by a shallow
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